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Petroleum Geology of the Whitewater Field Area, Southwestern Manitoba

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INTRODUCTION

General Introduction

The purpose of this study is to assess the oil reservoir properties of the Whitewater Field of southwestern Manitoba. To accomplish this, the following information is presented:

- the stratigraphy of the Mississippian Lodgepole Formation
- a summary of the history of exploration activity within the Whitewater Field
- a description of the lithologies of the Upper and Lower Whitewater Lake and Upper Virden Members of the Lodgepole Formation
- trapping mechanisms
- reservoir characteristics

Located predominantly in Township 3, Range 21 WPM (Fig. 1), the Whitewater Field is part of the Whitewater Lake Member and Virden Member subcrop belts of Mississippian (Lodgepole Formation) age. This regional subcrop trend encompasses the Lulu Lake Field to the southeast, and the Souris Hartney and Virden Fields to the northwest.

Production in the Whitewater Field is obtained primarily from the Upper and Lower Whitewater Lake Members. Minor production is also obtained from the Upper Virden Member.

As of June 1986, a total of 40 wells had been drilled within the Whitewater Field resulting in 26 oil producers, 1 pressure maintenance water injection well (a former producer), 2 salt water disposal wells (both former producers), 1 abandoned water supply well, and 10 dry and abandoned holes.

The three designated pools within the Whitewater Field include: Lodgepole WL A, Lodgepole WL B and Lodgepole Virden A. The discovery well for the Whitewater Field, Chevron Whitewater 12-16-3-21 WPM, was completed in the Upper Whitewater Lake Member in 1953 and led to the designation of the Lodgepole WL A Pool.

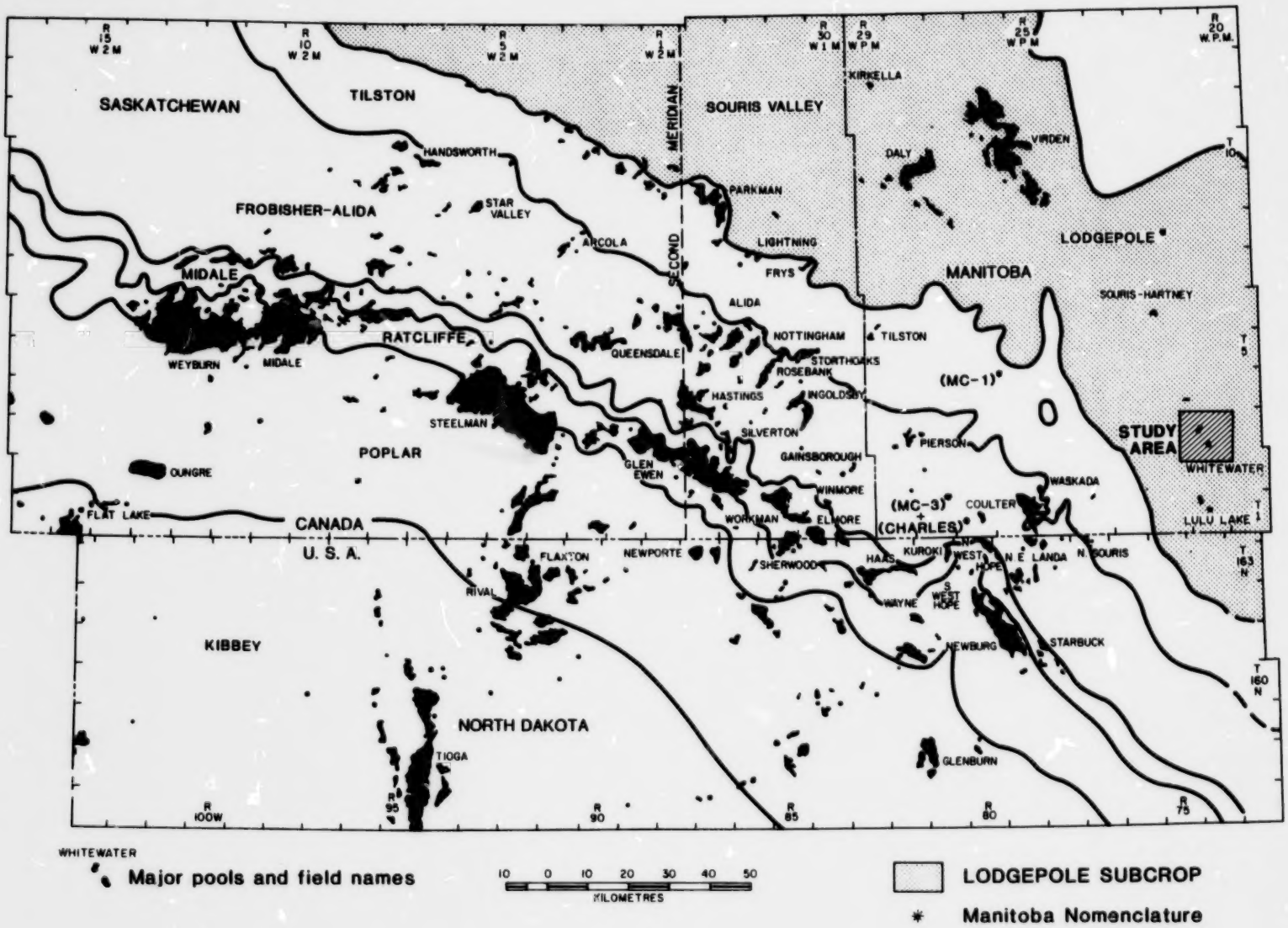

Figure 1: Location of Whitewater Field Study Area and Mississippian subcrop belts

In 1982, the well Roxy et al Whitewater 16-2-3-21 WPM was completed in the Lower Whitewater Lake Member, initiating the designation of the Lodgepole WL B Pool.

In 1985, the well Roxy-Andex Whitewater 9-2-3-21 WPM became the first well to produce from the Upper Virden Member. This resulted in the designation of the Lodgepole Virden A Pool.

The Lodgepole WL A Pool of the Whitewater Field was unitized in 1971, with Chevron as the operator, and named Whitewater Unit #1. Secondary oil recovery was introduced in this Pool in 1971 through waterflooding.

Geological Setting

Southwestern Manitoba is located on the northeastern flank of the Williston Basin. Sedimentary rocks of Paleozoic and Mesozoic age occur in this region forming a basinward-thickening wedge to the southwest. A major angular unconformity separates the Paleozoic rocks from the Mesozoic strata and probably represents one or more periods of erosion occurring from late Mississippian to early Jurassic time. During that interval, Paleozoic strata were tilted basinward which resulted in the progressive truncation of these strata toward the basin margin. Deposition was resumed during Mesozoic time, when a thick sequence of Jurassic and Cretaceous strata was deposited on the eroded Paleozoic surface.

General Stratigraphy

Mississippian strata within the Whitewater Field dip regionally southwestward toward the centre of the Williston Basin at an average of 6 metres per kilometre (31.5 feet per mile). They are divided, in ascending order, into the Bakken Formation and the Lodgepole Formation of Lower Mississippian Madison Group. The Mission Canyon and Charles Formations, which overlie the Lodgepole Formation, are both eroded within the Whitewater Field.

Strata within the Mississippian represent a major marine transgressive-regressive cycle (McCabe, 1959). During the initial advancement of Mississippian seas, the basal black shales and siltstones of the Bakken Formation were deposited over the eroded Devonian. Continued subsidence in the Williston Basin resulted in deposition of the limestones of the Lodgepole Formation. Several small-scale transgressive-regressive sequences of cyclical sedimentation were superimposed during (middle) Lodgepole time. These subcycles are represented in the Virden and Whitewater Lake Members of the Lodgepole Formation by a cyclic repetition of oolitic and/or crinoidal limestones.

In the Whitewater Field, the porous reservoir beds of the Lodgepole Formation, specifically, the Virden and Whitewater Lake Members, are truncated at the erosion surface. These porous beds are overlain by the Lower Amaranth "Red Beds" Formation of Jurassic age. An impermeable anhydrite-dolomite alteration zone at the Mississippian erosion surface, along with the overlying impermeable "Red Beds", acts as caprock for the oil accumulation.

Stratigraphic Nomenclature

The Lodgepole Formation constitutes the lowermost portion of the Madison Group of early Mississippian age. It is correlative with the Bottineau Interval (Lodgepole) of North Dakota and the Souris Valley Beds of southeastern Saskatchewan.

The stratigraphic terminology used in this report is that proposed by Stanton (1958) and McCabe (1963). Within the Field area, the Lodgepole Formation is subdivided into four members (Fig. 2) and they are in ascending order: Scallion, Virden (Lower and Upper), Whitewater Lake (Lower and Upper) and Flossie Lake.

The type section used for correlations of these members within the Whitewater Field is given in Figure 3 (in pocket).

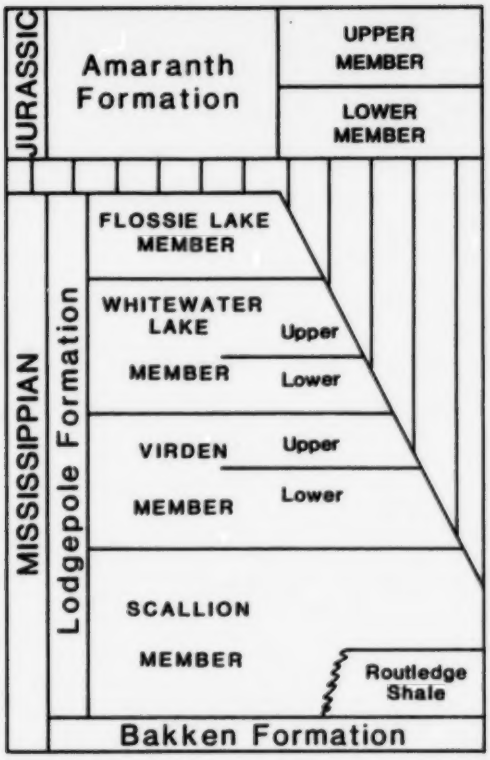

Figure 2: Stratigraphic Column (after Young and Greggs, 1975)

The Scallion Member lies conformably on the Bakken Formation. It consists of white to medium grey, finely crystalline to chalky, cherty limestones. On the SP log it is characterized by a clean, negative response (Fig. 3).

Overlying the Scallion Member is the lower unit of the Virden Member. The Virden Member represents the lower of the two cycles of deposition developed within the upper portion of the Lodgepole Formation. The Lower Virden Member consists of cyclically interbedded, light to buff oolitic limestone lentils and mottled grey to maroon argillaceous limestones. These lentils have been defined and are easily correlated throughout the Virden Field to the north, but are less easily traced in the Whitewater Field area. For this reason, the Lower Virden Member is not subdivided in the Whitewater Field area. The Lower Virden Member is marked lithologically by an increase in the argillaceous content relative to the underlying Scallion Member. On the SP log, this contact is picked at the first shale break above the clean SP log response of the Scallion.

The Upper Virden Member consists primarily of clean crinoidal limestone and displays a uniform negative SP log character. The upper limit of the unit is marked by an abrupt contact with an overlying red to purple, calcareous shale or shaly limestone. This shale marks the base of the Lower Whitewater Lake Member, and is often referred to in field terminology as the "Virden Shale".

The lower unit of the Whitewater Lake Member represents the basal portion of the second cycle of deposition developed within the Lodgepole Formation of the study area. Similar in lithology and log response to the Lower Virden, the Lower Whitewater consists of interbedded oolitic limestone and grey to maroon calcareous shale or argillaceous limestone. An oolitic "lentil" is developed within the basal portion of the unit and is present locally in the Whitewater Field area. The upper contact of the Lower Whitewater Lake Member is marked by a sharp decrease in argillaceous content.

The upper unit of the Whitewater Lake Member consists mainly of oolitic-bioclastic limestone. Its upper limit is picked as the top of the clean, blocky SP log response of the Upper Whitewater Lake Member. Lithologically, this contact is marked by the gradation from bioclastic limestone to an overlying argillaceous limestone.

The Flossie Lake Member, completes the Lodgepole sequence in this area. It consists mainly of argillaceous limestones and bands of secondary anhydrite, and forms a north-northwest-trending subcrop belt along the western boundary of the Whitewater Field area.

Shales and siltstones of the Lower Amaranth "Red Beds" Formation unconformably overlie the Flossie Lake Member.

EXPLORATION AND DEVELOPMENT HISTORY

Three pools have been designated in the Whitewater Field: Lodgepole WL A Pool (06 52A), Lodgepole WL B Pool (06 52B) and Lodgepole Virden A Pool (06 53A) (Fig. 4). The discovery of each of these pools, and development of wells within them, are discussed in the following synopsis of exploration and development history. Information presented was derived using production and well data available to June 30, 1986. Tables 1, 2 and 3 give a complete summary of production for wells within the three pools, Lodgepole WL A, Lodgepole WL B and Lodgepole Virden A.

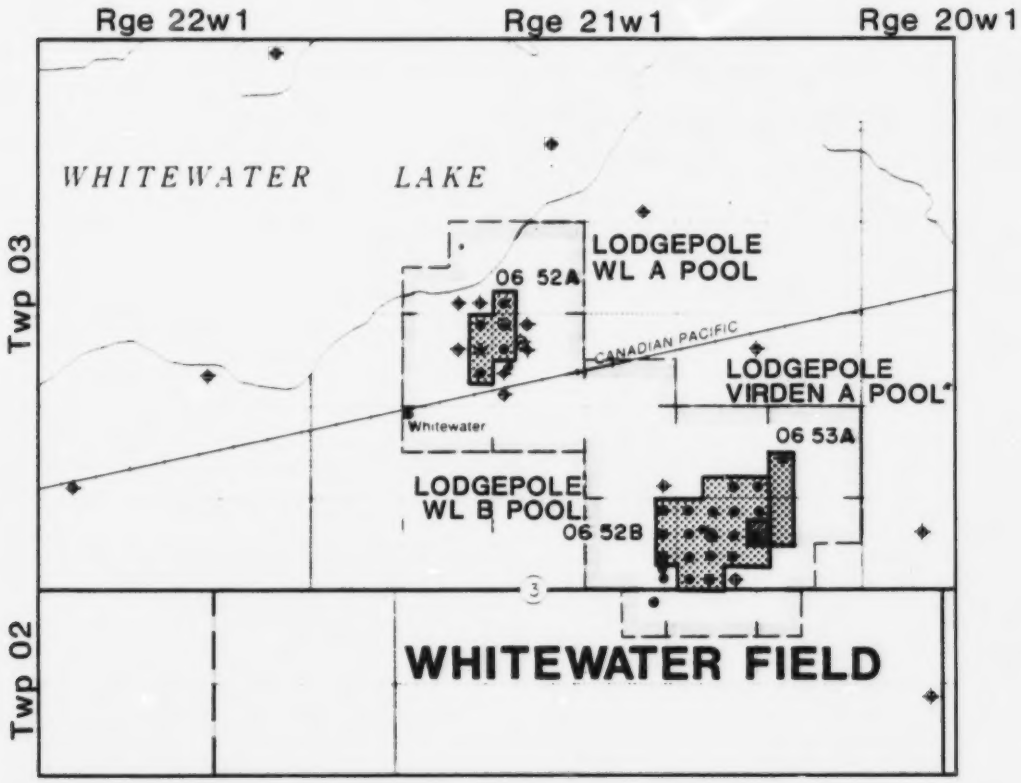

Figure 4: Plat showing pool designations within the Whitewater Field

Lodgepole WL A Pool

The Lodgepole WL A Pool was discovered in September of 1953 by California Standard. The discovery well, Chevron Whitewater 12-16-3-21 WPM, was completed in the Upper Whitewater Lake Member with 6.1 m (20') of net pay (McCabe, 1963). Initial production for the first year averaged 5.2 m^3/day of 855 kg/m^3 (34° A.P.I.) oil. The well is still on production, and as of June 30, 1986, had produced 21 102.4 m^3 oil and 16 293.1 m^3 water.

In 1954, four development wells were drilled by California Standard (now Chevron). These were 9-17-3-21 WPM and 16-17-3-21 WPM, 8-17-3-21 WPM and 13-16-3-21 WPM. All were completed in the Upper Whitewater Lake Member. Two of these wells, 8-17-3-21 WPM and 16-17-3-21 WPM are still active producers.

In 1955, the well Chevron Whitewater (formerly Northern Development Whitewater) 4-21-3-21 WPM was drilled and completed in the Upper Whitewater Lake Member. The well was suspended in 1968 as uneconomic, but resumed production in 1973, following reconditioning.

Between 1955 and 1985, seven unsuccessful development wells were drilled. The well Chevron Whitewater WSW 11A-16-3-21 WPM, was drilled in 1972 as a water source well in the Lower Cretaceous Swan River Formation and subsequently abandoned in August of 1985.

In July of 1971, the wells within the Lodgepole WL A Pool were unitized with Chevron as operator and secondary oil recovery by waterflooding was initiated. In 1972, 9-17-3-21 WPM and 13-16-3-21 WPM were converted to water injection. Subsequently, 13-16-3-21 WPM was converted to a salt water disposal well in 1985.

Development activity resumed in January of 1986, when Tundra Oil & Gas drilled and completed the Tundra Whitewater A5-16-3-21 WPM well in the Upper Whitewater Lake Member.

Lodgepole WL B Pool

Drilling by Roxy et al in 1982 led to the discovery of the Lodgepole WL B Pool three and one-half kilometres southeast of the original Lodgepole WL A Pool. The discovery well, Roxy et al Whitewater 16-2-3-21 WPM was completed in the Lower Whitewater Lake Member.

Three development wells were drilled by Roxy Petroleum Ltd. ("Roxy") and Andex Oil Co. Ltd. ("Andex") during the same year: 15-2-3-21 WPM, 1-11-3-21 WPM and 2-11-3-21 WPM. The first two wells were completed in the Lower Whitewater Lake Member and the third well was completed in both the Upper and Lower Whitewater Lake Members. All three are still active producers.

In 1983 Roxy and Andex drilled six additional development wells: 6-2-3-21 WPM, 10-2-3-21 WPM, 11-2-3-21 WPM, 12-2-3-21 WPM, 13-2-3-21 WPM and 14-2-3-21 WPM. All wells were completed in both the Upper and Lower Whitewater Lake Members, with the exception of 11-2-3-21 WPM and 12-2-3-21 WPM which were completed in the Upper Member only. Five of the six wells are presently producing. The 11-2-3-21 WPM well was converted to a salt water disposal well in June of 1984.

In 1984 Roxy and Andex drilled two more wells: 3-2-3-21 WPM and 5-2-3-21 WPM. Both were completed in the Upper Whitewater Lake Member and are still producing.

Another five development wells were drilled by Roxy and Andex in 1985. These include: 4-2-3-21 WPM, 7-2-3-21 WPM, 9-2-3-21 WPM, A11-2-3-21 WPM and 9-3-3-21 WPM. All wells were completed in the Upper Whitewater Lake Member, with the exception of 9-2-3-21 WPM. The 9-2-3-21 WPM was originally completed in the Upper Virden Member, but was recompleted a month later in the Lower Whitewater Lake Member.

In 1986 four additional development wells were drilled within the Lodgepole WL B Pool. The three wells at 1-3-3-21 WPM, A8-3-3-21 WPM and 16-3-3-21 WPM, drilled by Roxy and Andex, were completed in the Upper Whitewater Lake Member. The fourth well, Chevron Whitewater 16-33-3-21 WPM,

drilled by Chevron, was also completed in the Upper Whitewater Lake Member. All four wells are active producers at present.

Lodgepole Virden A Pool

In 1985, Roxy-Andex Whitewater 9-2-3-21 WPM became the first well to produce from the Upper Virden Member. It was recompleted a month later in the Lower Whitewater Lake Member.

A second well, Roxy-Andex Whitewater 5-12-3-21 WPM, drilled in 1985, was also completed in the Upper Virden Member. It remains as the only Virden Member producer within the Whitewater Field.

TABLE 1

PRODUCTION HISTORY
Whitewater Lodgepole WL A Pool
(Pool Code 06 52A)

WELL LOCATION	INITIAL ON PRODUCTION DATE (M/Y)	AVERAGE DAILY PRODUCTION (1st yr. of production) (m^3/day)		AVG. WATER CUT 1st year of production (%)	CUMULATIVE PRODUCTION to June 30, 1986 (m^3)		AVG. DAILY PRODUCTION (1985) (m^3)		AVG. WATER CUT 1985 Production (%)
		OIL	WATER		OIL	WATER	OIL	WATER	
A5-16 03 21 WPM	01/86	0.51	0.04	7	45.3	3.8			
12-16 03 21 WPM	10/53	5.21	0.06	1	21 102.4	16 293.1	0.67	6.67	91
Transferred to Whitewater Unit #1, 8/31/72									
13-16 03 21 WPM	12/54	5.20	0.02	0.4	15 736.47	74.57			
Converted to Water Injection Well 8/31/72									
Transferred to Whitewater Unit #1 July 1/71					(Cumulatives based on production to 12/31/72)				
08-17-03-21 WPM	08/54	3.51	0.19	5	4 700.1	6 297.8	0.25	7.49	97
Transferred to Whitewater Unit #1 July 1/71									
09-17-03 21 WPM	03/54	1.58	0.02	1	1 171.7	58.5			
Converted to Water Injection Well 8/31/72					Production suspended since 1960				
Transferred to Whitewater Unit #1 July 1/71					(Cumulatives based on production to 12/31/59)				
16-17 03 21 WPM	04/54	7.86	0.13	2	30 674.9	24 460.7	0.50	5.75	92
Transferred to Whitewater Unit #1 July 1/71									
04 21 03 21 WPM	10/55	1.24	0.02	2	2 093.2	2 755.6	0.17	5.02	97

TABLE 2

PRODUCTION HISTORY
Whitewater - Lodgepole WL B Pool
(Pool Code 06 52B)

WELL LOCATION	INITIAL ON PRODUCTION DATE (M/Y)	AVERAGE DAILY PRODUCTION (1st yr. of production) (m^3/day)		AVG. WATER CUT 1st year of production (%)	CUMULATIVE PRODUCTION to June 30, 1986 (m^3)		AVG. DAILY PRODUCTION (1985) (m^3)		AVG. WATER CUT 1985 Production (%)
		OIL	WATER		OIL	WATER	OIL	WATER	
16-33-02-21 WPM	04/86	12.38 (based on May and June production values)	2.03	14	594.0	57.1			
03-02-03-21 WPM	02/84	4.81	0.15	3	2 838.9	181.5	2.13	0.36	14
04-02-03-21 WPM	12/85	3.52	0.36	9	1 080.6	130.8	5.70 (based on June/86 production values)	1.04	15
05-02-03-22 WPM	01/84	1.79	5.23	75	1 773.0	1 202.1	1.99	0.08	4
06-02-03-21 WPM	10/83	6.43	0.18	3	3 956.0	128.0	3.62	0.09	3
07-02-03-21 WPM	03/85	5.19	7.54	59	1 311.2	6 197.4	0.60	14.03	9.6
09-02-03-21 WPM Recompleted from 06-53A	05/85	2.69	15.94	86	767.8	7 075.1	1.55	18.60	92
10-02-03-21 WPM	07/83	6.87	8.16	54	3 370.5	2 104.3	2.19	0.08	4
11-02-03-21 WPM	10/83	0.55	0.10	15	82.0 (up to and including May/84)	40.3	Converted to Salt Water Disposal		
All-02-03-21 WPM	01/86	0.67	0.10	13	58.7	8.8			
12-02-03-21 WPM	12/83	8.51	0.02	2	5 414.8	5 865.4	2.80	10.57	79
13-02-03-21 WPM	01/84	11.22	1.04	8	3 613.8	2 286.2	1.83	1.46	44
14-02-03-21 WPM	11/83	5.38	0.44	8	2 829.7	401.9	2.37	0.37	14
15-02-03-21 WPM	01/85	2.83	11.30	80	2 339.3	19 108.5	1.50	20.98	93
16-02-03-21 WPM	05/82	3.46	3.89	53	3 160.1	20 947.4	1.98	22.50	92

TABLE 2 (cont'd)

PRODUCTION HISTORY
Whitewater Lodgepole WL B Pool
(Pool Code 06 52B)

WELL LOCATION	INITIAL ON PRODUCTION DATE (M/Y)	AVERAGE DAILY PRODUCTION (1st yr. of production) (m^3/day)		AVG. WATER CUT 1st year of production (%)	CUMULATIVE PRODUCTION to June 30, 1986 (m^3)		AVG. DAILY PRODUCTION (1985) (m^3)		AVG. WATER CUT 1985 Production (%)
		OIL	WATER		OIL	WATER	OIL	WATER	
01 03 03 21 WPM	02/86	11.69	1.18	9	1 046.0	99.6			
A8 03 03 21 WPM	03/86	7.91	6.94	47	608.70	534.2			
09 03 03 21 WPM	03/85	7.72	4.77	38	3 017.3	2 944.0	5.25	9.16	64
16 03 03 21 WPM	02/86	5.5	8.82	62	530.8	786.2			
01 11 03 21 WPM	01/83	3.14	6.98	69	1 845.4 (No production in June/86)	12 991.5	1.38	18.87	93
02 11 03 21 WPM	01/83	2.22	11.27	84	1 960.8	16 736.5	1.40	19.06	93

TABLE 3

PRODUCTION HISTORY
Whitewater Lodgepole Virden A Pool
(Pool Code 06 53A)

WELL LOCATION	INITIAL ON PRODUCTION DATE (M/Y)	AVERAGE DAILY PRODUCTION (1st yr. of production) (m^3/day)		AVG. WATER CUT 1st year of production (%)	CUMULATIVE PRODUCTION to June 30, 1986 (m^3)		AVG. DAILY PRODUCTION (1985) (m^3)		AVG. WATER CUT 1985 Production (%)
		OIL	WATER		OIL	WATER	OIL	WATER	
09 02 03 21 WPM (Recompleted to 06 52B May 24/85)	05/86	0.85	10.34	92	11.9 (Total production - month of May/85)	144.7			
05 12 03 21 WPM	05/85	2.47	0.87	26	1 416.6	437.6	0.48	1.40	74

GEOLOGY

Lithology

Seven cores were examined within the designated study area (Appendix). Selection of core was based on availability and recovery of cored intervals. Lithologic descriptions were based on Dunham's (1962) classification of limestones and Choquette and Pray's (1970) classification of carbonate porosity types.

The following is a summary of the lithologies found in the Upper Virden and Upper and Lower Whitewater Lake Members. It should be noted that this report does not attempt any detailed petrologic or diagenetic analysis, but merely outlines the major lithologies within the Whitewater Field.

a) Upper Virden Member

Few cores of the Upper Virden Member were available for description. However, those cores examined indicated that the Upper Virden Member consists of calcite-cemented packstone/grainstones. The Upper Virden Member reaches a maximum thickness of 7.3 m.

b) Lower Whitewater Lake Member

The Lower Whitewater Lake Member consists of oolitic packstone/grainstones and wackestone/packstones interbedded with wackestone/mudstones and shales. The packstone/grainstones are buff to brown, oolitic, fossiliferous and display good moldic and inter-oolitic porosity. A well developed oolitic packstone/grainstone "lentil" occurs (locally) within the basal portion of the unit. Lower Whitewater Lake production is obtained primarily from this "lentil".

The wackestone/packstones are pink to brown, oolitic, fossiliferous and display fair to good moldic and intergranular porosity. Grains are cemented by calcite. The wackestone/mudstones are light grey-green to maroon, bioclastic (shell, crinoid and brachiopod fragments), locally hematite stained, and display fair moldic porosity.

Shales within this Member are maroon to light green, calcareous, fissile and fossiliferous.

The Lower Whitewater Lake Member reaches a maximum depositional thickness of 13.5 m within the study area.

c) Upper Whitewater Lake Member

The Upper Whitewater Lake Member consists of buff to brown, bioclastic (crinoids and brachiopods), oolitic packstones that display fair to good interparticle and pinpoint porosity. The packstones are interbedded with pink to brown, bioclastic (corals and brachiopods) wackestones displaying fair intergranular porosity. Grains within the wackestones are, in places, infilled with anhydrite.

Maximum recorded thickness of the Upper Whitewater Lake Member reaches 15 m* within the study area. (*note: includes altered zone)

d) Altered Zone

The altered zone is not a discrete lithology as those described for the aforementioned Member but, rather, is a diagenetic feature related to processes occurring at the erosion surface. Within the study area, the altered zone occurs immediately below the unconformity surface, reaching a maximum thickness of 6.7 m. According to Zakus (1967), the dolomitization and anhydritization is believed to have occurred during the deposition of the overlying Amaranth beds, when magnesium-rich, and later calcium sulphate-rich, waters percolated down and altered the Mississippian limestones. The impermeable nature of the Lower Whitewater Lake Member largely limited further downward percolation and subsequent alteration. Thus, limestones of the Lower Whitewater Lake Member and the underlying Virden Member, where capped by Lower Whitewater Lake shales, have remained largely unaltered.

Alteration is most evident or extensive in the Upper Whitewater Lake Member, which subcrops throughout a large part of the study area. Little or no effects of dolomitization or anhydritization are seen within the Lower

Whitewater Lake Member and the Upper Virden Member. Only where these Members have been exposed at the erosion surface are any effects of alteration observed.

Structure/Isopach

The Whitewater Field area is located within the subcrop belt of the Whitewater Lake and Virden Members. The Upper Whitewater Lake beds constitute the subcrop unit throughout most of the Field and the majority of producing wells have been completed in the subcropping Upper Whitewater Lake Member at or near the Mississippian unconformity (Fig. 5).

Structure contours on the Mississippian marker beds, specifically the Lower Whitewater Lake Member, Figure 6, indicate minor structural deformation in the Field area. For the most part, the surface is fairly regular and follows a regional southwest dip. "Highs", however, are observed at the northwestern (WL A) pool of the Field, represented by a small closure, and at the southeastern (WL B) pool, represented by a southwest-trending nose.

Structure on the surface of the overlying Upper Whitewater Lake Member is also fairly uniform, following the regional southwest dip (Fig. 7). Contours within the Upper Whitewater Lake subcrop belt, representing structure on the Mississippian erosion surface (Fig. 5), show two well-defined closures at both the WL A and WL B Pools (Fig. 7). These "highs" are coincident with, but more prominent than, those viewed on the underlying Lower Whitewater Lake Member.

An isopach map of the Upper Whitewater Lake Member (Fig. 8) indicates a general erosional thinning toward the eastern edge of the subcrop belt. Preserved "thicks" occur as isolated pods at the WL A and WL B Pools, where closure is evident on the eroded Upper Whitewater Lake surface.

Depositional thickness of the Upper Whitewater Lake Member appears to increase westward within the study area (Fig. 8). True depositional trends, however, could not be determined in the western part of the map area due to

limited well control. Therefore, the isopach contours downdip from the Upper Whitewater Lake subcrop belt, which represent depositional isopachs, are inferred.

"Highs" on the erosion surface (Figs. 5 and 7) are outlined by thinning of the overlying Lower Amaranth "Red Beds" (Fig. 9). Northeast-southwest-trending isolated Red Bed "thins" are noted near the erosion limit of the Upper Whitewater Lake subcrop belt, corresponding to the closed "highs" of the underlying Upper Whitewater Lake Member erosion surface. Thinning of the "Red Beds" over "highs" on the erosion surface indicates that these features are likely paleotopographic in origin and are due to differential erosion (McCabe, 1963).

The structure of the top of the "Red Beds" (Fig. 10), is a subdued expression of the Mississippian erosion surface and follows the regional southwest dip. Slight relief is present on the "Red Bed" surface over the Mississippian (Upper Whitewater Lake Member) "paleotopographic highs", which may be an indication of post-depositional differential compaction within the Lower Amaranth sediments.

a) Trapping Mechanisms

Control for oil accumulation in the Whitewater Field appears to be primarily stratigraphic in nature. Truncation of the porous reservoir beds of the Upper Whitewater Lake Member (and similarly those of the Lower Whitewater Lake and Upper Virden Members) has resulted in the formation of a series of stratigraphic traps.

The following is a scenario outlining the formation of these stratigraphic traps. During Mississippian erosion, the Upper Whitewater Lake Member was preserved as a series of "erosional" or "paleotopographic highs", represented by closures on the eroded top of the Upper Whitewater Lake Member (Fig. 7) and by isopach thicks along the eastern edge of the Upper Whitewater Lake subcrop belt (Fig. 8). Following erosion, the Lower Amaranth "Red Beds" were deposited over the erosion surface, infilling the lows as shown by the

isopach map of the "Red Beds" (Fig. 9) and later compacting to conform to the underlying unconformity surface, as represented by slight structural expressions on the "Red Bed" surface (Fig. 10).

Although slight highs on marker beds within the Mississippian indicate some deformation within the Field area (Fig. 6), structure appears to play a minor role in the overall trap setting (McCabe, 1963, Steinborn, 1985). Exact timing of these slight structural highs is not determinable, but is likely to have been post-Mississippian/pre-Jurassic in age.

Dolomitization and anhydritization occurred during the deposition of the Amaranth beds, when magnesium-rich and later calcium sulphate-rich waters percolated down through the sediments, altering the underlying Mississippian limestones. The impermeable nature of the Lower Whitewater Lake Member largely limited further downward percolation and subsequent alteration. As a result, the limestones of the Lower Whitewater Lake Member and underlying Upper Virden Member have remained unaltered.

It is evident from cross-sections that the "paleotopographically high" areas within the Whitewater Field are not as extensively anhydritized and dolomitized as the surrounding areas (McCabe, 1963), resulting in an increase in the "porosity closure" off the flanks of these "highs".

The structural cross-sections $A\text{-}A^1$ and $B\text{-}B^1$ along dip (Figs. 11 and 12, in pocket) depict the distribution of the three pools within the Field. These sections illustrate the stratigraphic trapping as a result of both the progressive eastward truncation of the reservoir beds and variations in thickness of the altered zone.

Section $C\text{-}C^1$ (Fig. 13, in pocket) shows the distribution of the pools along strike. It appears that the extent of alteration is greater in the northern part of the Field (WL A Pool) than in the south (WL B Pool and Virden A Pools). Where the altered zone has not provided a "cap", the overlying Lower Amaranth "Red Bed" shales provide the seal for the reservoir.

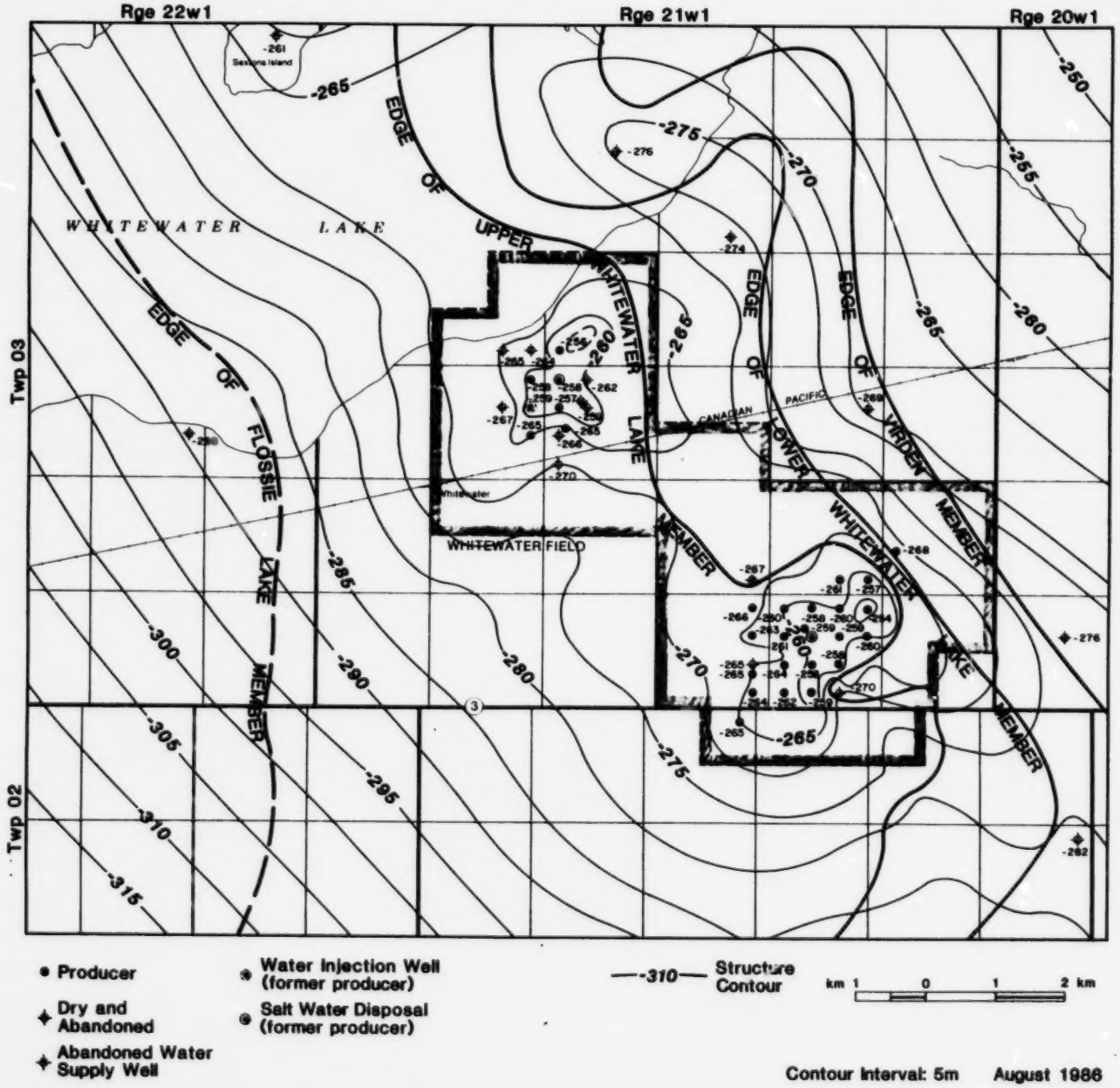

Figure 5: Structure Map on the Mississippian Erosion Surface

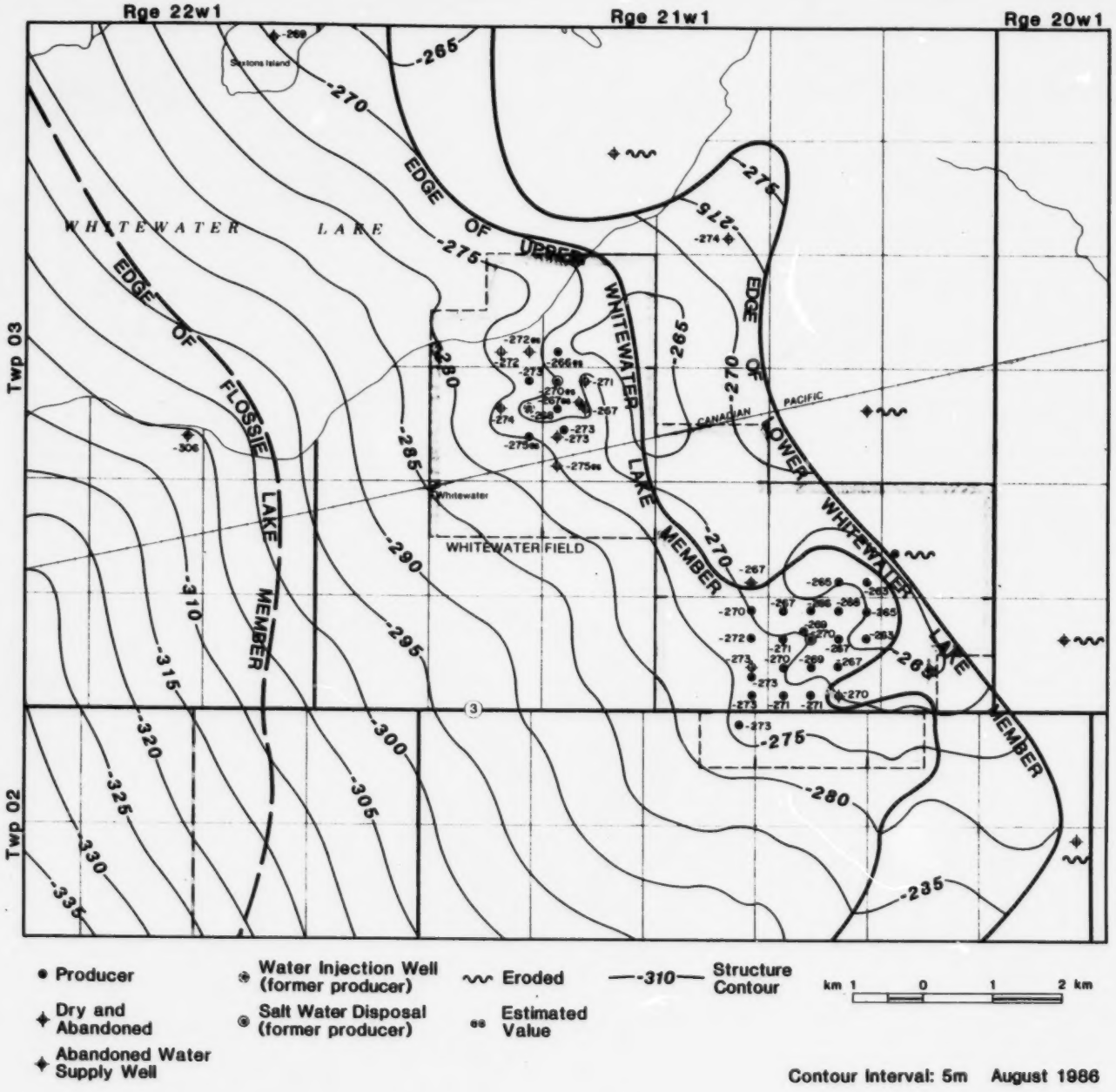

Figure 6: Structure Map on the Lower Whitewater Lake Member

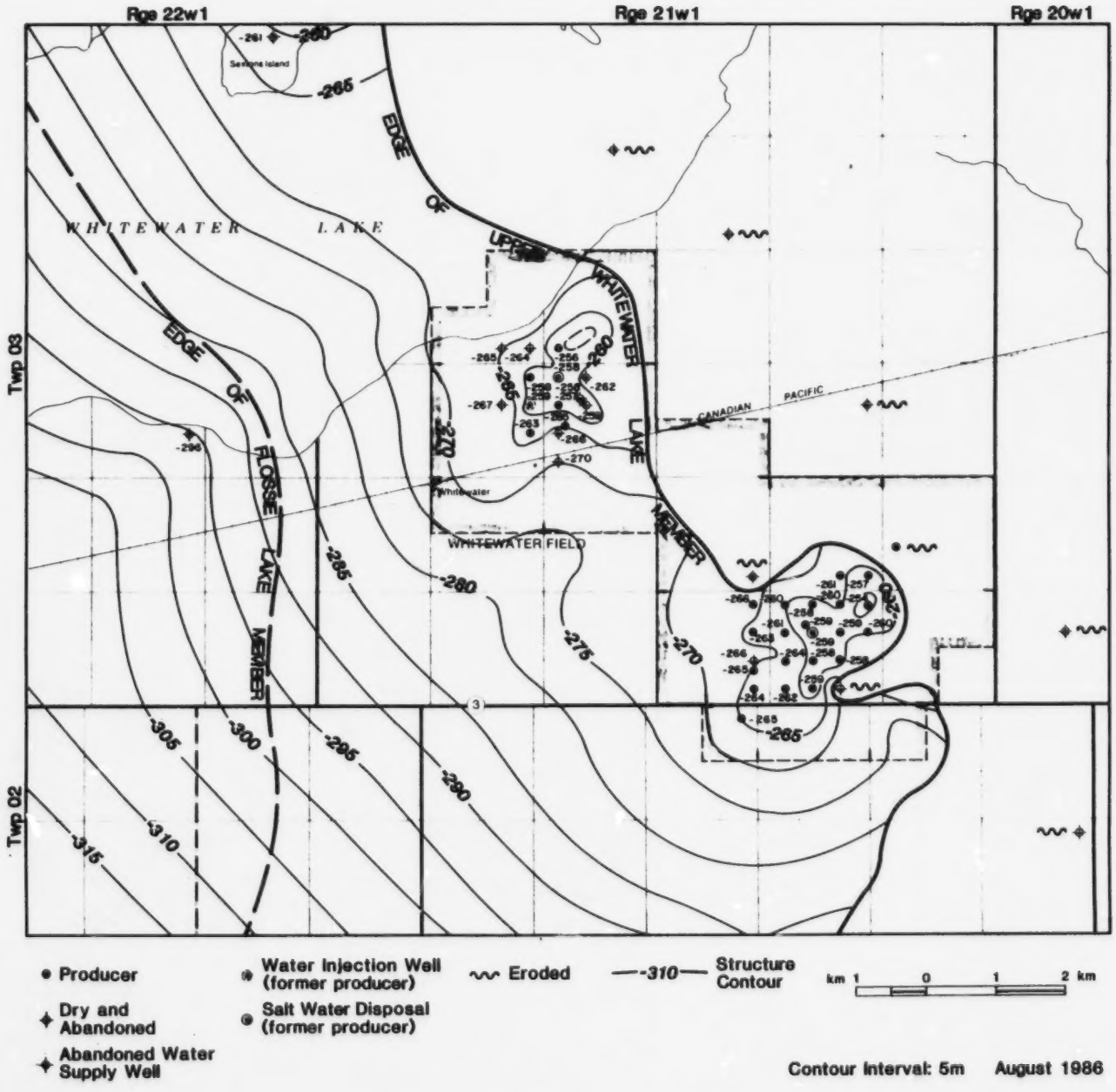

Figure 7: Structure Map on the Upper Whitewater Lake Member

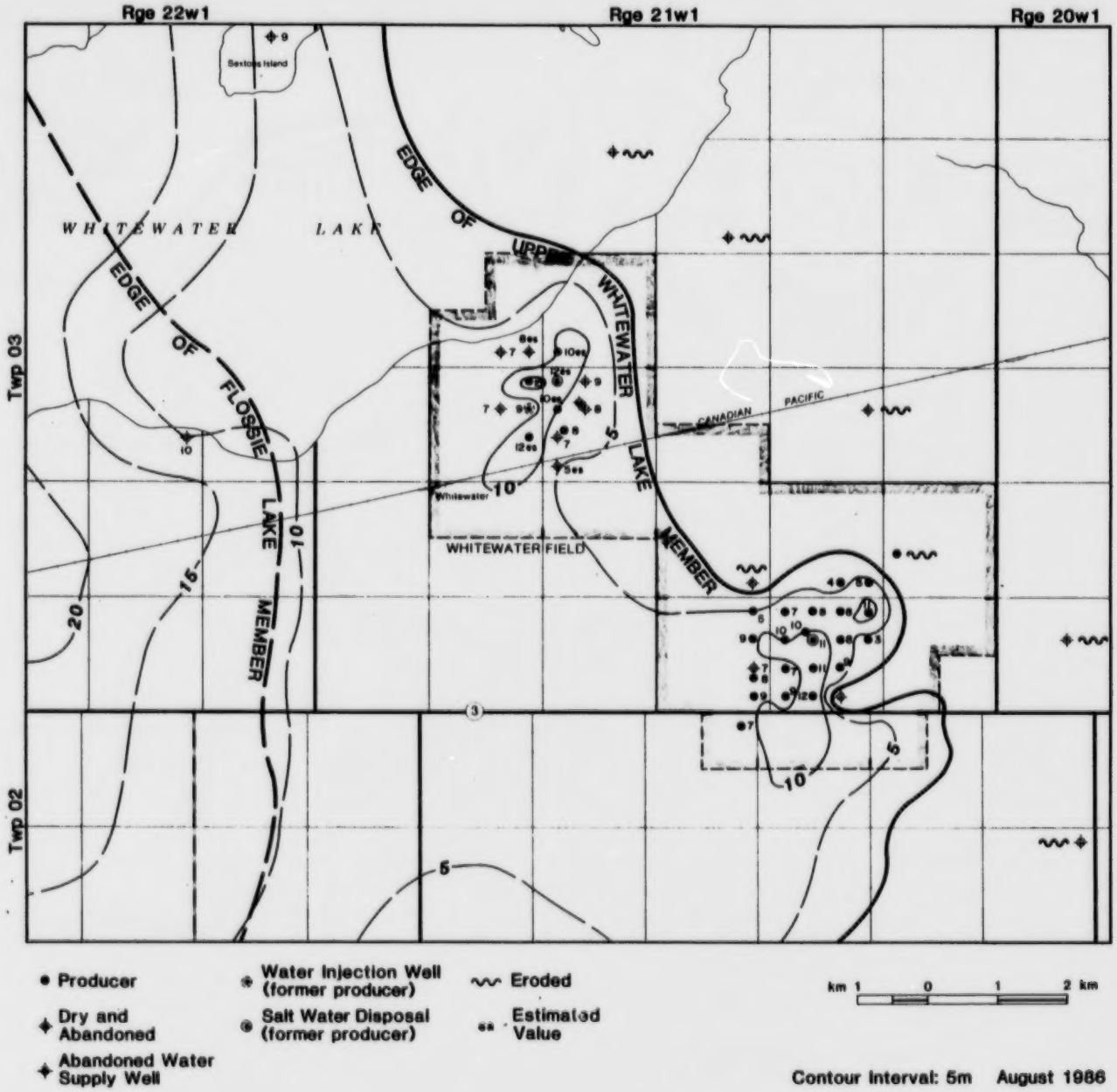

Figure 8: Isopach Map of the Upper Whitewater Lake Member (top of Lower Whitewater Lake Member to top of Mississippian erosion surface; including alteration zone)

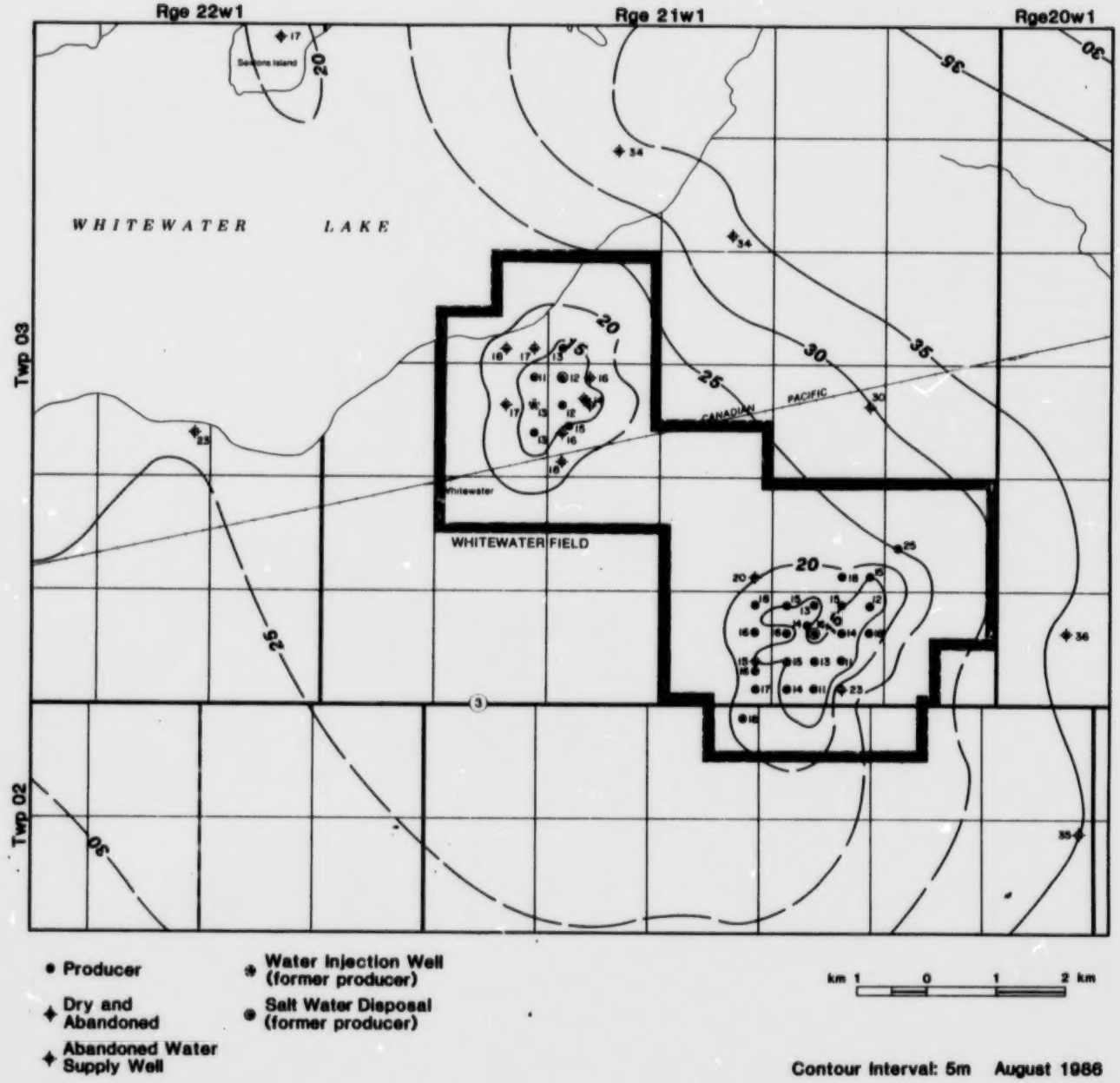

Figure 9: Isopach Map of the Lower Amaranth "Red Beds" Formation

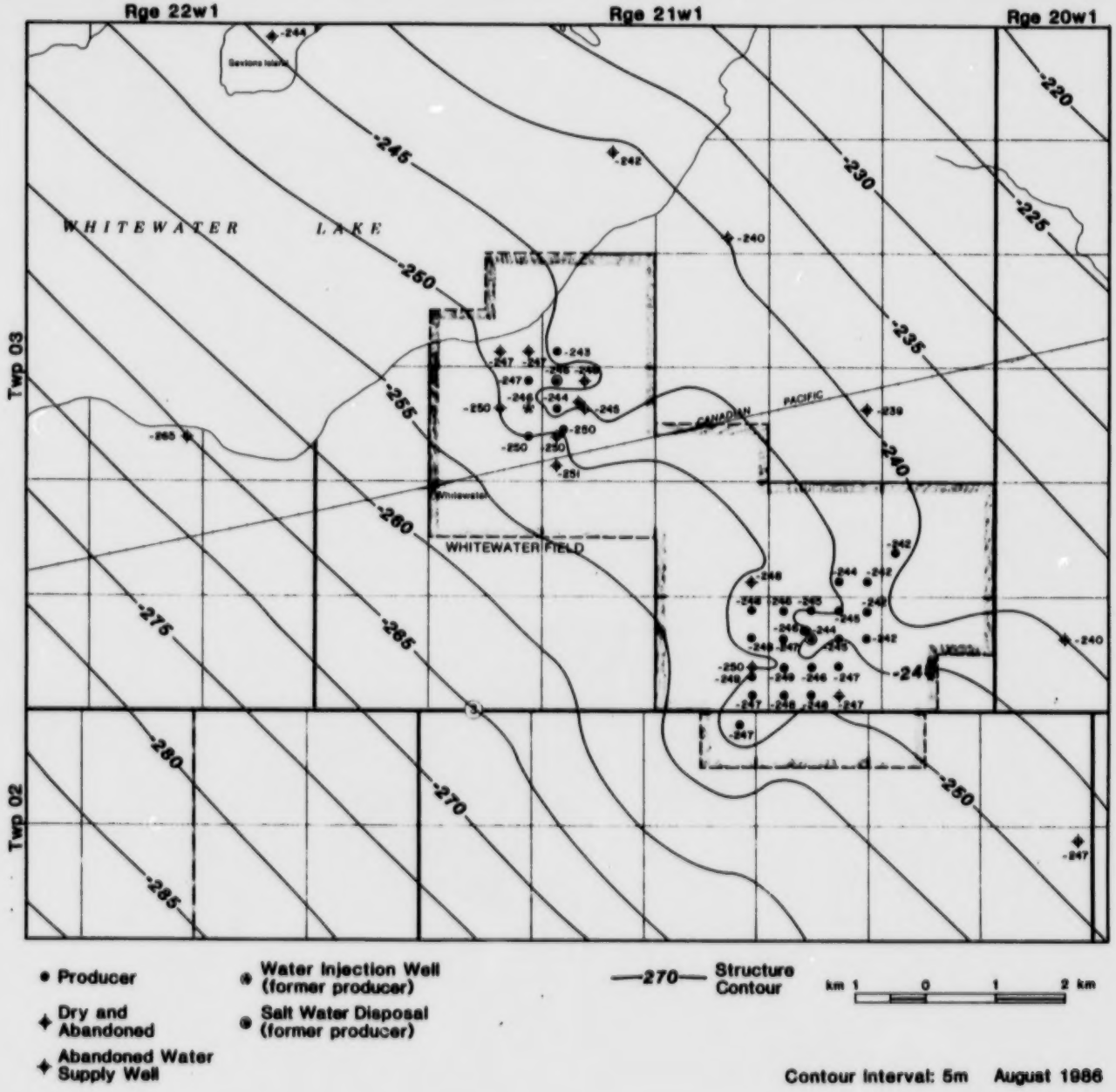

Figure 10: Structure Map on the Lower Amaranth "Red Beds" Formation

ENGINEERING PROPERTIES

By correlating logs to core data in the Lulu Lake, Mountainside and Whitewater Areas, some important reservoir properties have been obtained for the Whitewater Lodgepole WL B Pool ("WL B Pool"). Whitewater Lake Member porosities, permeabilities, water saturations, net pay thicknesses and oil-in-place estimates have been calculated and mapped, when possible, for the WL B Pool. The methodology used to determine these properties as well as their description are presented in Figures 14 to 25 and Tables 4 to 8 and are discussed in this section of the report. As previously noted, all reservoir engineering properties were obtained and mapped on data available to June 30, 1986. Cummulative production and remaining recoverable reserve estimates are calculated to the end of the 1985 production year.

Reservoir property calculations for the Whitewater Lodgepole WL A Pool ("WL A Pool") have been omitted from this section of the report since there is insufficient petrophysical data available to calculate accurate reservoir properties for this Pool. The WL A Pool is basically depleted and inactive, with the exception of three producers which, in total, presently produce from 30 to 40 m^3 of oil per month.

Methodology

a) Log Trace Normalization

Prior to conducting log calculations for wells in the WL B Pool, the deep resistivity and sonic travel time log traces for each well were compared to a set of standard or average log traces. This comparison was made to identify and correct inconsistencies in log calibration. Because the Cretaceous Morden Shale exhibits very consistent resistivity log responses throughout the WL B Pool area, it has been assumed that Morden Shale porosities are consistent throughout the area as well. Average Morden Shale log responses have been determined and log traces for all of the wells in the WL B Pool have been compared and corrected to these Morden Shale standard log responses.

Figure 14 shows a set of typical log trace responses in the Morden Shale. The average depth of the shale in the WL B Pool area is 412 metres KB. The log traces on the left track of Figure 14 are the resistivity curves. The dashed curve represents the deep or true resisitivity. Based on all available data in the area, Rsh or the deep resisitivity for the Morden Shale is consistently 3 ohm-metres. The value Rsh = 3 ohm-metres is considered to be the standard deep resisitivity response in the Morden Shale for the WL B Pool area. The log trace on the right track of Figure 14 is the sonic travel time curve. Based on all available data, the average Δt or sonic travel time reading in the Morden Shale is 482 msec/m. The value Δt = 482 msec/m is considered to be the standard response in the Morden Shale for the WL B Pool area.

Table 4 lists all the average Morden Shale Rsh and Δt responses for each well in the WL B Pool area. With the exception of only two wells, all Rsh values are 3 ohm-metres. No Rt corrections were applied to any of the wells in the area. Sonic travel time values more often deviate from the standard value of 482 msec/m. The consistency of Rsh in the Morden Shale in the area should ideally be reflected in consistent Δt readings from well to well. Inconsistencies in Δt probably result from the fact that the sonic tool is a more sensistive instrument than the deep resistivity tool. Corrections applied to the Δt trace in the Morden Shale to obtain the standard value of 482 msec/m are listed in the Δt correction column of Table 4. The sonic traces for each well have been adjusted by the amounts in this column. The well A11-2, for example, has an average Morden Shale Δt response of 474 msec/m and a corresponding correction of +8. The sonic travel time trace for this well has been increased by 8 msec/m from KB to TD.

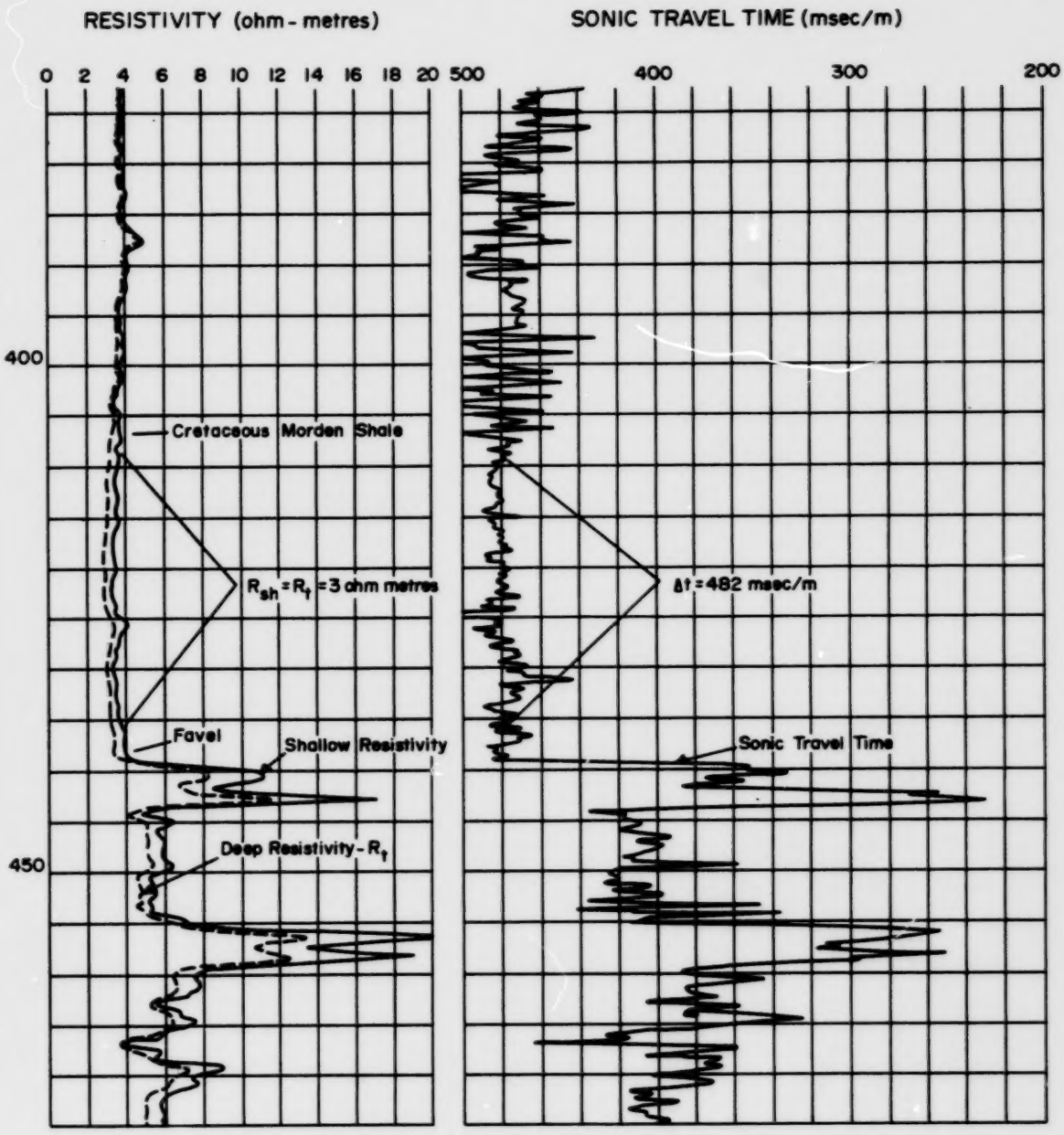

Figure 14: Cretaceous Morden Shale Log Traces in the Whitewater Lodgepole WL B Pool Area

TABLE 4: Normalization of Log Traces in Whitewater Lodgepole WL B Pool

Location	Top of Morden Shale (m, KB)	Rsh (ohm-m)	Δt (Msec/m)	Δt Correction (482* - Δt) (msec/m)
16-33-02-21	425	2.9	no sonic	uncorrected
03-02-03-21	425	3.0	486	-4
04-02-03-21	420	3.0	480	+2
05-02-03-21	415	3.0	480	+2
06-02-03-21	420	3.0	no sonic	uncorrected
07-02-03-21	420	3.0	485	-3
09-02-03-21	415	3.0	481	+1
10-02-03-21	410	3.0	no sonic	uncorrected
11-02-03-21	410	3.0	no sonic	uncorrected
A11-02-03-21	410	3.0	474	+8
12-02-03-21	410	3.0	480	+2
13-02-03-21	410	3.0	483	-1
14-02-03-21	405	3.0	480	+2
15-02-03-21	410	3.0	485/noisy	-3
16-02-03-21	410	3.0	488	-6
01-03-03-21	425	2.8	480	+2
08-03-03-21	420	3.0	480	+2
8A-03-03-21	420	3.0	458/noisy-1 ft. sonic	+24
09-03-03-21	410	3.0	482	0
16-03-03-21	400	3.0	485	-3
01-10-03-21	400	3.0	485	-3
01-11-03-21	400	3.0	480	+2
02-11-03-21	400	3.0	490	-8
05-12-03-21	400	3.0	482	0

Average top = 412 m *Average Δt = 482 msec/m

b) Derivation of Whitewater Lake Member and Upper Virden Member Porosities

A study by Martiniuk and Arbez (1986) includes a sonic travel time versus core porosity crossplot for the Upper Whitewater Lake Member for the Lulu Lake, Mountainside and Whitewater areas (see Fig. 15). The crossplot shows a good correlation of sonic travel time to core porosity (correlation coefficient = 0.85). The following correlation was obtained from the crossplot and is used in this report to obtain Upper Whitewater Lake Member porosities:

$$\phi_c = \frac{\Delta t - 166}{299}$$

where: ϕ_c = core porosity in decimal fractions

Δt = sonic travel time in msec/m

The above correlation is also used to obtain porosities in the Lower Whitewater Lake Member where the Member appears to have good reservoir development (where there is a low radiation count on the gamma ray log). The Upper Whitewater Lake and Upper Virden Members are geologically similar in the WL B Pool area. The above correlation is then also justifiably used to obtain Upper Virden Member porosities in the WL B Pool area.

c) Derivation of Whitewater Lake Member and Upper Virden Member Permeabilities and Definition of Permeability Cut-Off

A good correlation between permeability and core porosity was obtained for non-fractured Upper Whitewater Lake Member samples in a study by Martiniuk and Arbez (1986) for the Lulu Lake Field (Fig. 16). A permeability of 1 md is a generally accepted permeability cut-off for the production of oil from Mississippian producers in southwest Manitoba. This cut-off has been applied to the WL B Pool.

Figure 16 shows that a permeability of 1 md corresponds to a sonic porosity cut-off of 7.5%. Figure 15 shows that a 7.5% porosity corresponds to a sonic travel time of 188 msec/m. Those portions of the Upper Whitewater Lake Member which have a sonic travel time of less than 188 msec/m are excluded from average porosity, permeability, water saturation, net pay and

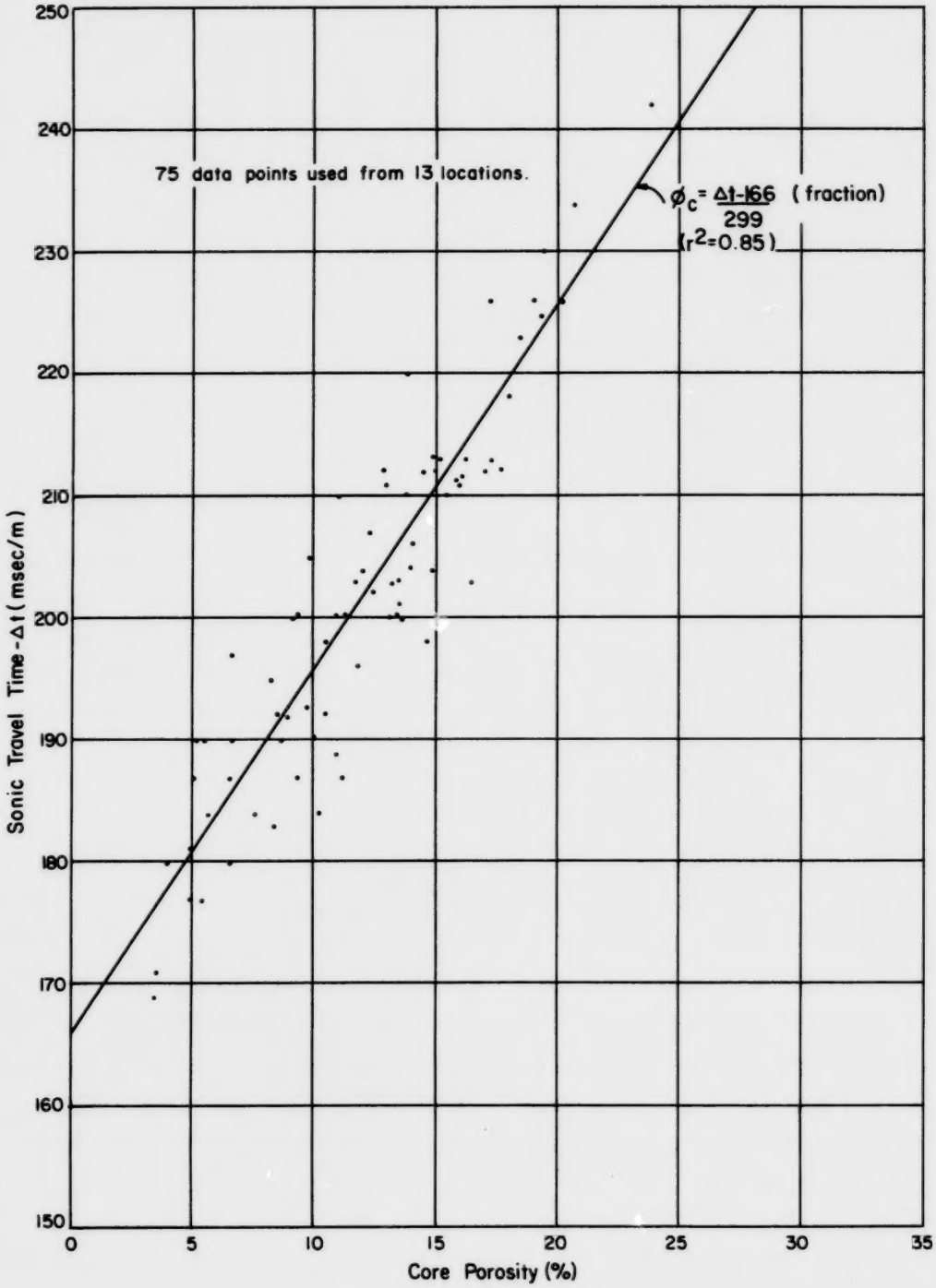

Figure 15: Sonic Travel Time Versus Core Porosity for Lulu Lake, Mountainside, Whitewater Areas (Upper Whitewater Lake Member)

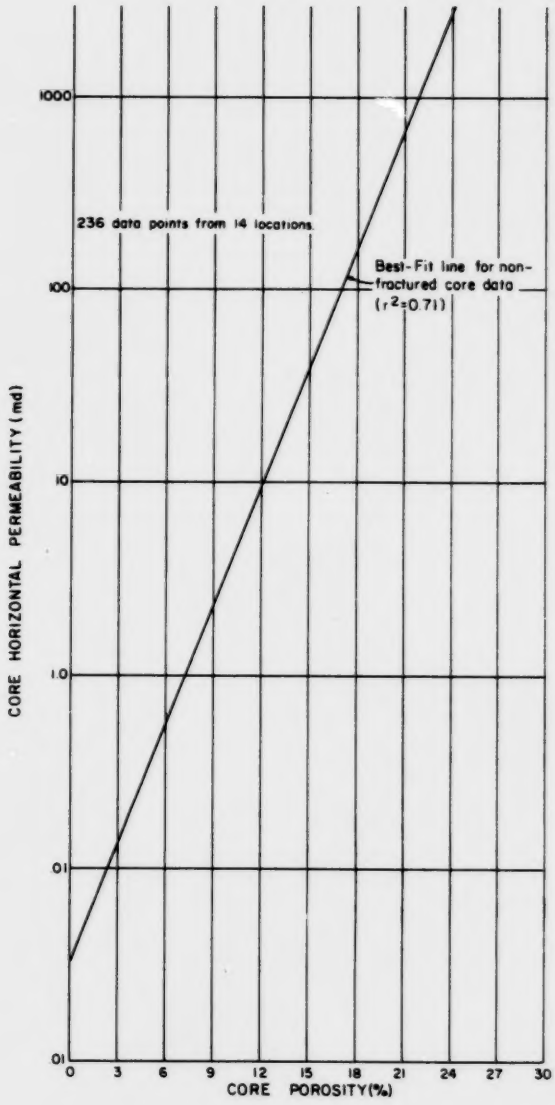

Figure 16: Permeability Versus Core Porosity for Non-Fractured Upper Whitewater Lake Samples

oil-in-place calculations. Because the Upper and Lower Whitewater Lake and Upper Virden Members are geologically similar within the WL B Pool area, the sonic travel time cut-off of 188 msec/m has been applied to all three zones.

d) Water Saturations

The basic "Archie" equation which is commonly used to calculate formation water saturation is:

$Sw^n = (aRw)/(\phi^m Rt)$ (1) where:

- a, m and n are Archie constants obtained from special core analyses (unitless)
- Sw is the water saturation (ranges from 0 to 1.0)
- Rw is the formation water resistivity (ohm-meters)
- Rt is the deep resistivity (ohm-metres)
- ϕ is the porosity (ranges from 0 to 1.0)

If Sw is set to 1.0,

then $Rt = Ro = aRw/\phi^m$ (2)

where Ro is the deep resistivity of a water-saturated formation.

Combining equations (1) and (2)

$Sw^n = Ro/Rt$ or $Rt = Ro/Sw^n$

The saturation exponent "n" was obtained from a special core analysis on an Upper Whitewater Lake Member core sample from the well 3-2-3-21 WPM. The factor "n" = 1.61.

The equation $Sw^{1.61} = Ro/Rt$ can be graphically represented for a set of different Sw values as seen in Figure 17. The Sw lines were obtained as follows.

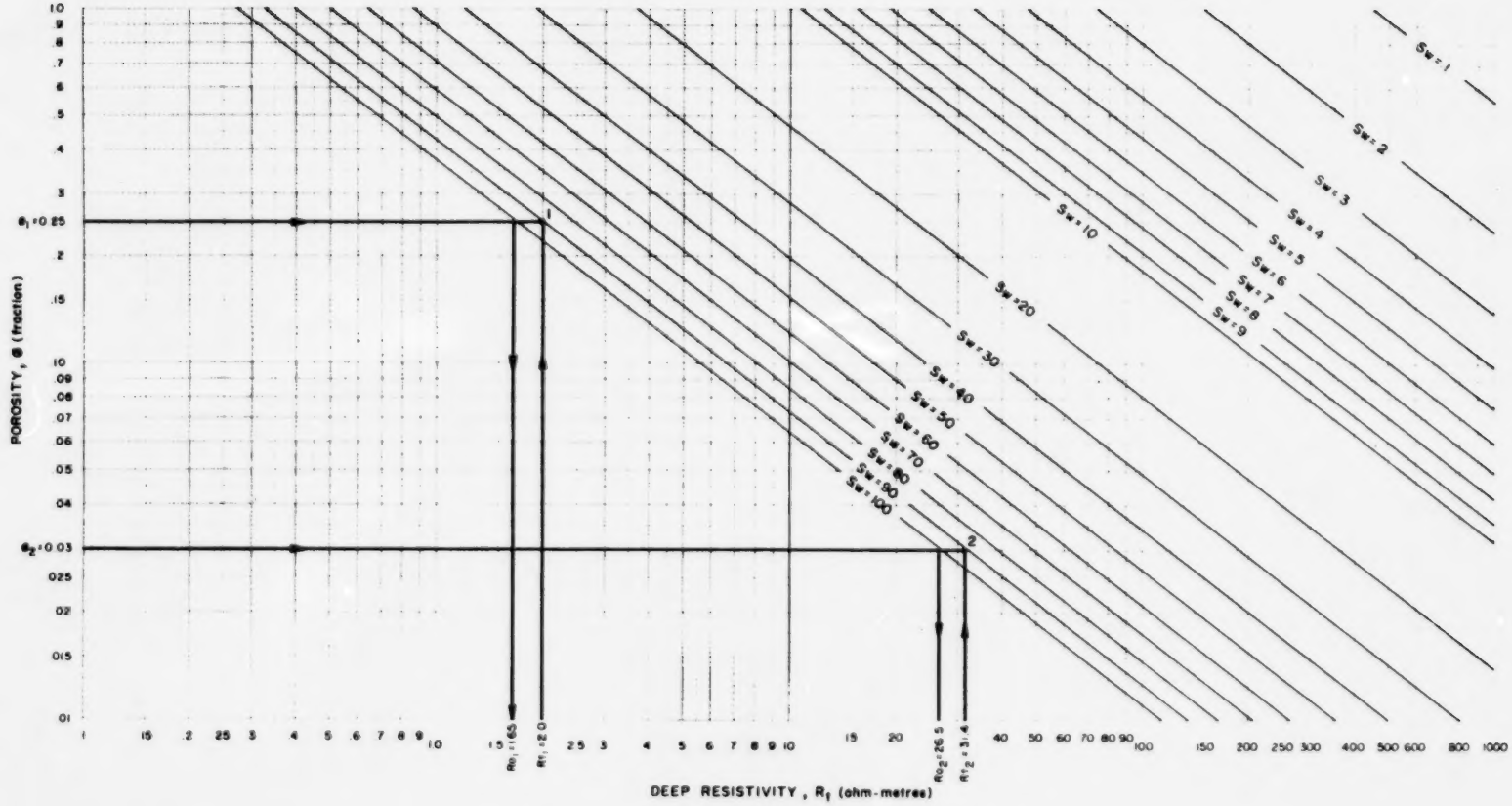

Figure 17: Porosity-Deep Resistivity Crossplot
(Upper Whitewater Lake and Upper Virden Members)

An Sw = 1.0 base line was first plotted. As previously noted, the Upper Whitewater Lake and Upper Virden Members are geologically similar in the WL B Pool area. Throughout most of the area, the Upper Virden Member is wet. Upper Virden porosities and corresponding log deep resistivities for all of the WL B Pool area wells were plotted on a porosity-deep resistivity crossplot similar to the one in Figure 17. A line through these points represents the Sw = 1.0 line in Figure 17.

The following example illustrates how the remaining Sw lines were obtained. Sw was set to 0.90 (or Sw = 90%) and ϕ was set to 0.25 (or ϕ = 25%). The intersection of the horizontal line ϕ = 0.25 and the Sw = 1.0 line yields an Ro value of 1.65. This Ro value theoretically represents the water-saturated formation deep resistivity when ϕ = 0.25. With the equation $Rt = Ro/Sw^{1.61}$, we calculate $Rt = 1.65/(0.90)^{1.61} = 2.0$ ohm-metres. The intersection of the vertical line Rt = 2.0 and the horizontal line ϕ = 0.25 is a point on the Sw = 0.90 line. To obtain a second point on the Sw = 0.90 line, we set ϕ = 0.03 and followed the same procedures. By joining the two Sw = 0.90 points with a straight line, the Sw = 0.90 line is drawn. All Sw lines were obtained this way.

Because a good Sw versus formation elevation (relative to sea level) correlation could not be obtained for the WL B Pool, no attempt was made to locate an oil/water contact for the Upper Whitewater Lake Member.

Description of Whitewater Lodgepole WL B Pool

a) Porosity - ϕ (Fig. 18)

Porosity contours trend in a northeast-southwest direction. Upper Whitewater Lake Member porosities range from 9 to 21%. The highest porosities have developed in the central portion of the Pool at the following locations: 4-2-3-21 WPM, 6-2-3-21 WPM, 10-2-3-21 WPM, 11-2-3-21 WPM 13-2-3-21 WPM and 15-2-3-21 WPM. Porosities decrease dramatically, away from the centre of the Pool.

The average porosity of the Upper and Lower Whitewater Lake Members for the WL B Pool is 14%.

b) Permeability - K (Fig. 19)

The permeability values for this figure were obtained from the permeability/porosity correlation in Figure 16. The average permeability of the Upper and Lower Whitewater Lake Members for the WL B Pool is 25 md.

c) Water Saturation - Sw (Fig. 20)

Using the crossplot on Figure 17, water saturations were obtained for each well. The average Whitewater Lake Member water saturation is 43%. Since there is very little variation in water saturation in the WL B Pool, it was not possible to obtain a correlation between water saturation and structure. The lowest water saturations are found in the north-central portion of the Pool at the well locations 11-2-3-21 WPM and 15-2-3-21 WPM.

d) Net Pay - h (Fig. 21)

The south-central portion of the WL B Pool (well locations 3-2-3-21 WPM, 4-2-3-21 WPM, 6-2-3-21 WPM, 7-2-3-21 WPM and 10-2-3-21 WPM) exhibits the best Upper Whitewater Lake Member net pays (greater than or equal to 7.0 metres). Net pay contours generally follow a northeast to southwest trend with pay decreasing rapidly, away from the centre of the Pool. Some of the net pay contours are truncated by the Upper Whitewater Lake Member subcrop edge on the east side of the Pool.

e) Original Oil-in-Place per Unit Area - Oh(1-Sw)

i) Upper Whitewater Lake Member (Fig. 22)

As expected, the greatest concentration of original oil-in-place appears to be located in the central portion of the WL B Pool. The wells 4-2-3-21 WPM, 6-2-3-21 WPM, 10-2-3-21 WPM, 11-2-3-21 WPM, 12-2-3-21 WPM and 14-2-3-21 WPM all have an original oil-in-place per unit area greater than 0.5 (m^3/m^2). The original oil-in-place contours generally follow the same northeast to southwest trend as the effective net pay contours, with original oil-in-place decreasing rapidly, away from the centre of the WL B Pool.

The north and east sides of the Pool are limited by the Upper Whitewater Lake Member subcrop edge. The extension of the Pool to the south and west is probably limited by decreasing porosity or poor reservoir development and possibly a downdip water zone.

There appears to be a limited amount of future drilling potential in the WL B Pool. The following five locations show some Upper Whitewater Lake Member potential: 13-34-2-21 WPM, 12-34-2-21 WPM (offset to the north), 14-34-2-21 WPM (offset to the west), 2-3-3-21 (offset to the east) and 3-11-3-21 WPM (offset to the south).

ii) Upper and Lower Whitewater Lake Members (Fig. 23)

This map is very similar to the Upper Whitewater Lake Member Original Oil-In-Place per Unit Area Map (Fig. 22) with the exception that any Lower Whitewater Lake Member potential is included. The addition of Lower Whitewater Lake Member potential extends the Pool boundary beyond the Upper Whitewater Lake Member subcrop edge and close to the Lower Whitewater Lake Member subcrop edge to the north and east.

The Original Oil-In-Place per Unit Area Map for the Upper and Lower Whitewater Lake Members (Fig. 23) shows that there may be a limited amount of Lower Whitewater Lake Member potential at the location 8-2-3-21 WPM (offset to the west).

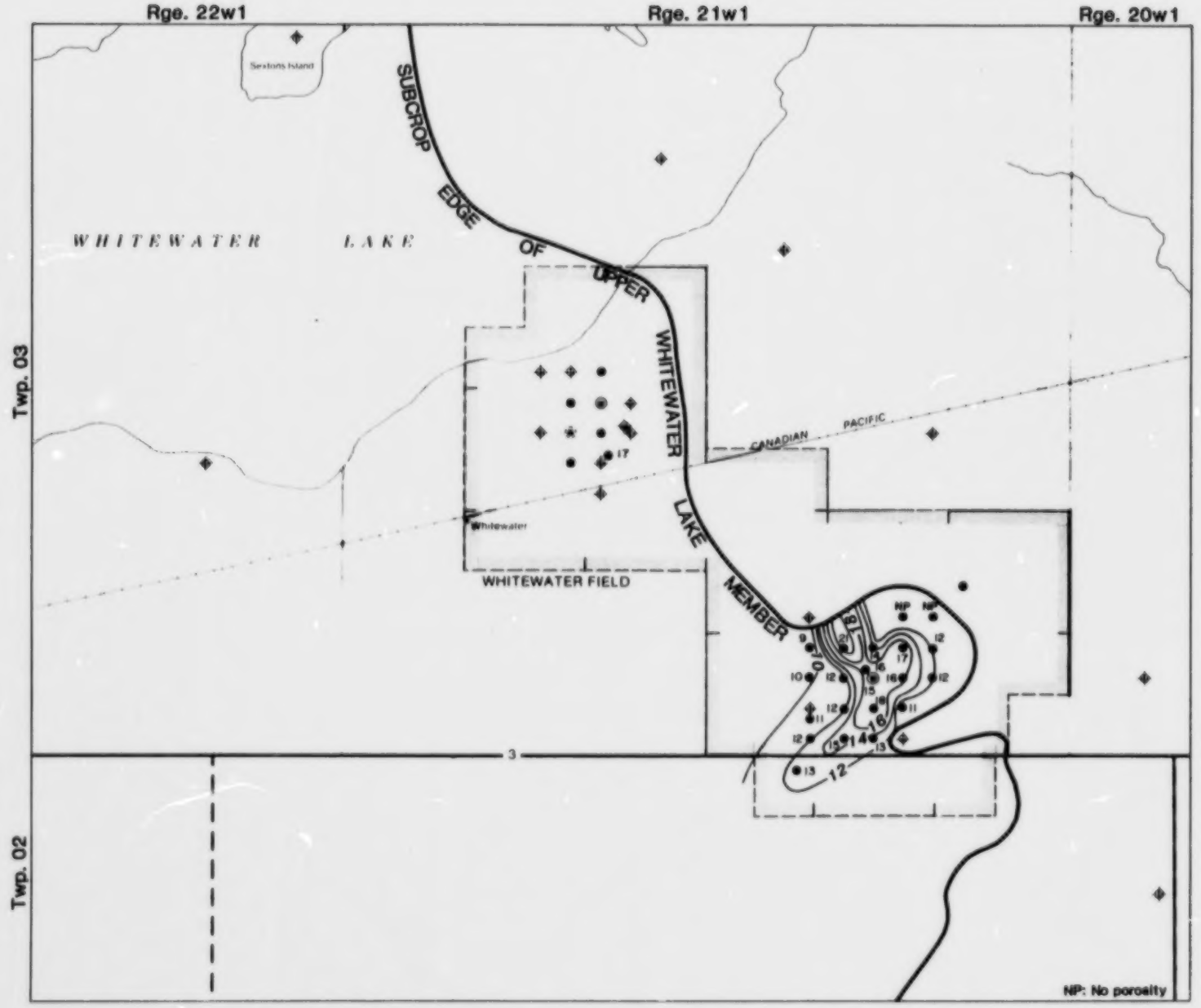

Figure 18: Porosity Map for Whitewater Lodgepole WL B Pool
(contour interval: 2%)

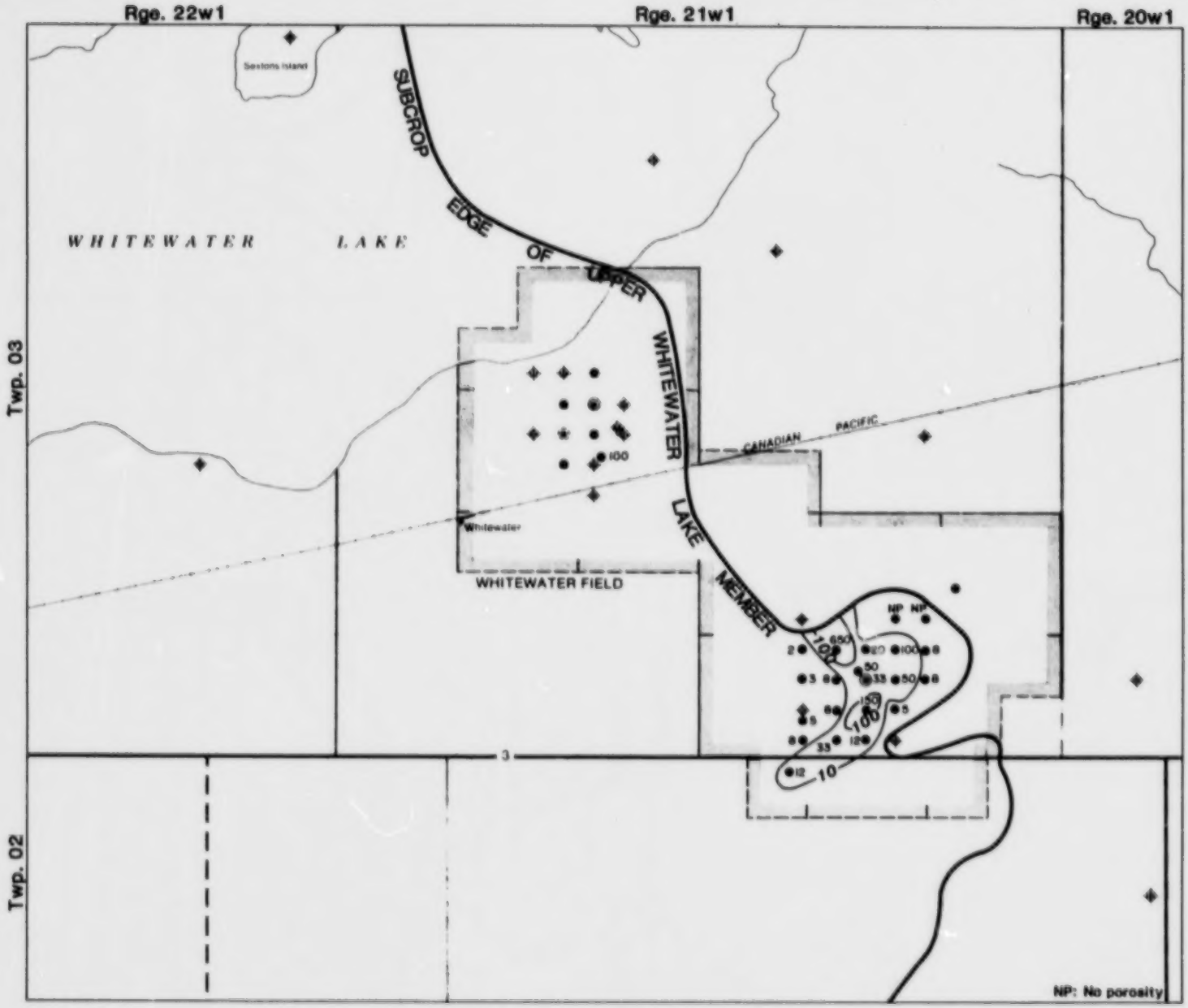

Figure 19: Permeability Map for Whitewater Lodgepole WL B Pool
(logarithmic contour interval, millidarcies)

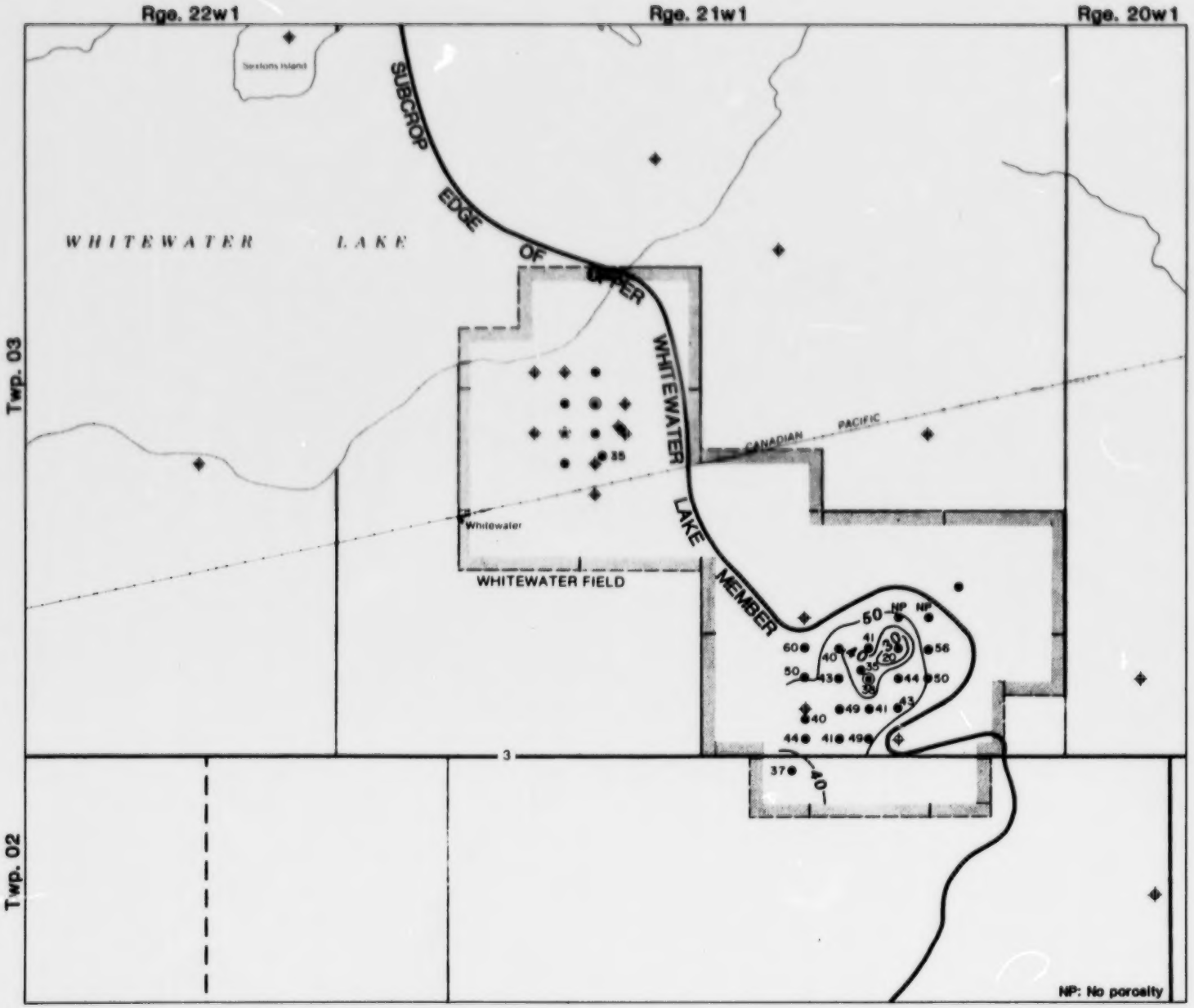

Figure 20: Water Saturation Map for Whitewater Lodgepole WL B Pool
(contour interval: 10%)

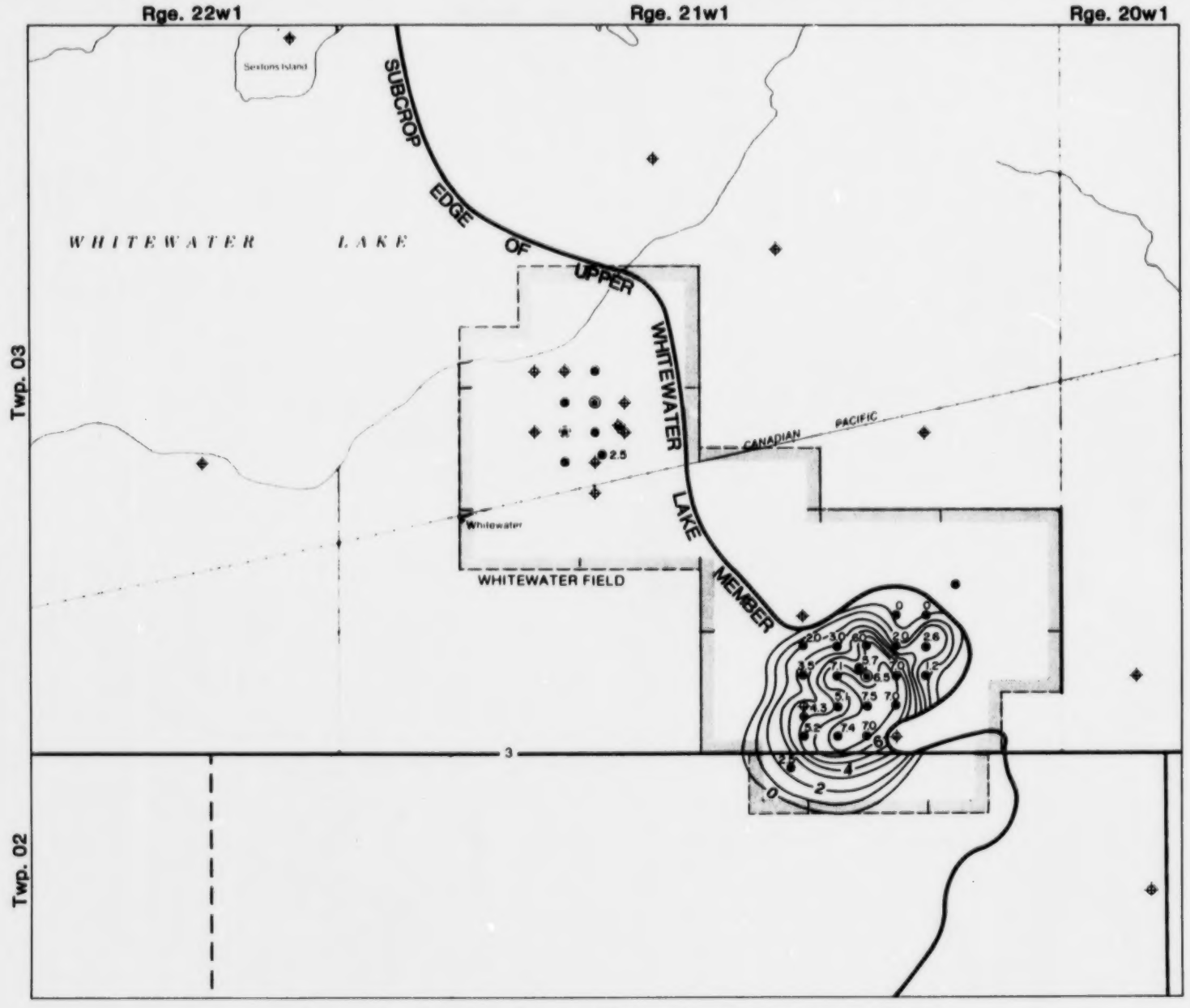

Figure 21: Net Pay Map for Whitewater Lodgepole WL B Pool
(contour interval: 1 metre)

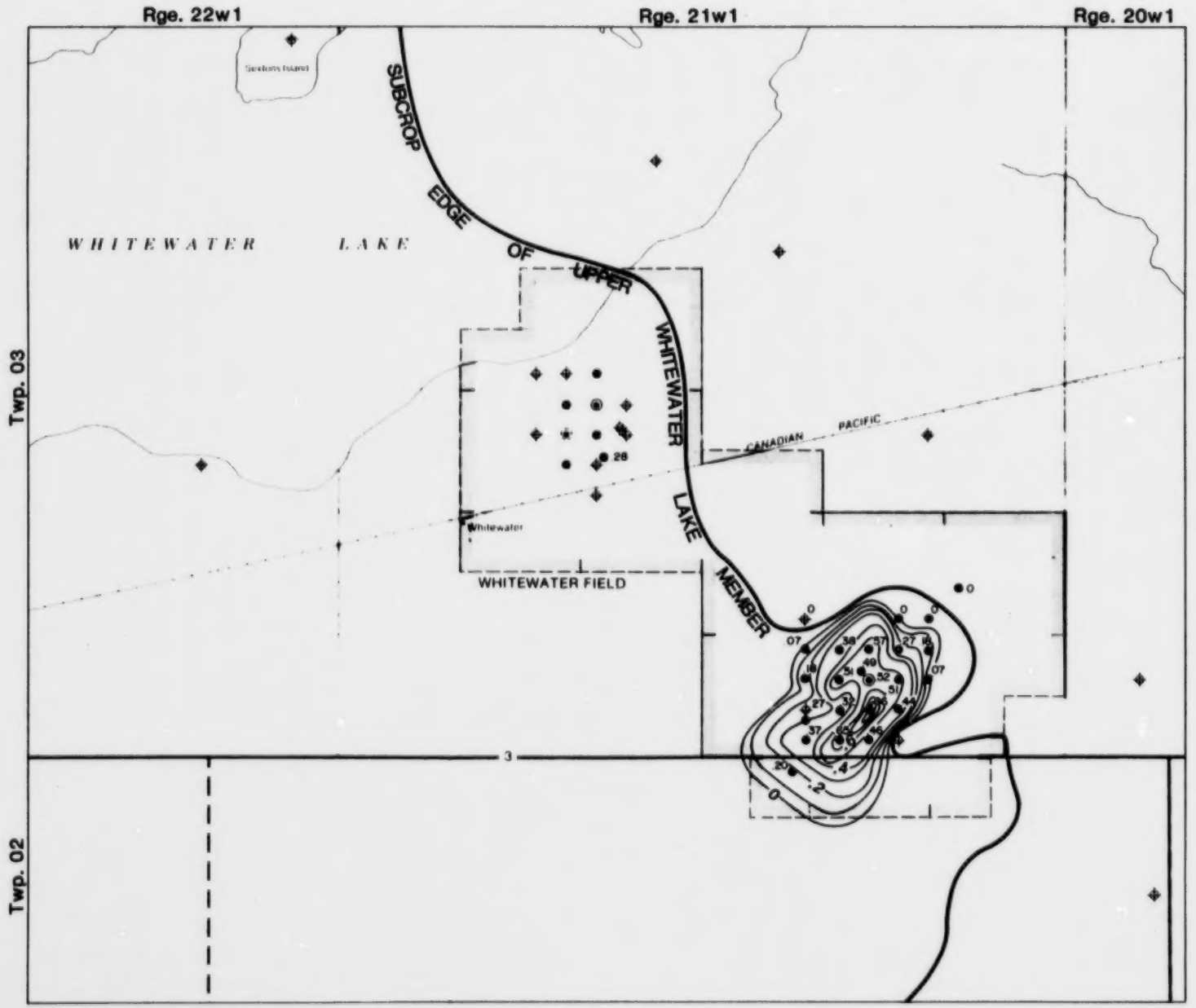

Figure 22: Oil-in-Place per Unit Area M[illegible]p for Upper Whitewater Lake Member (contour interval: 0.3m^3/m^3)

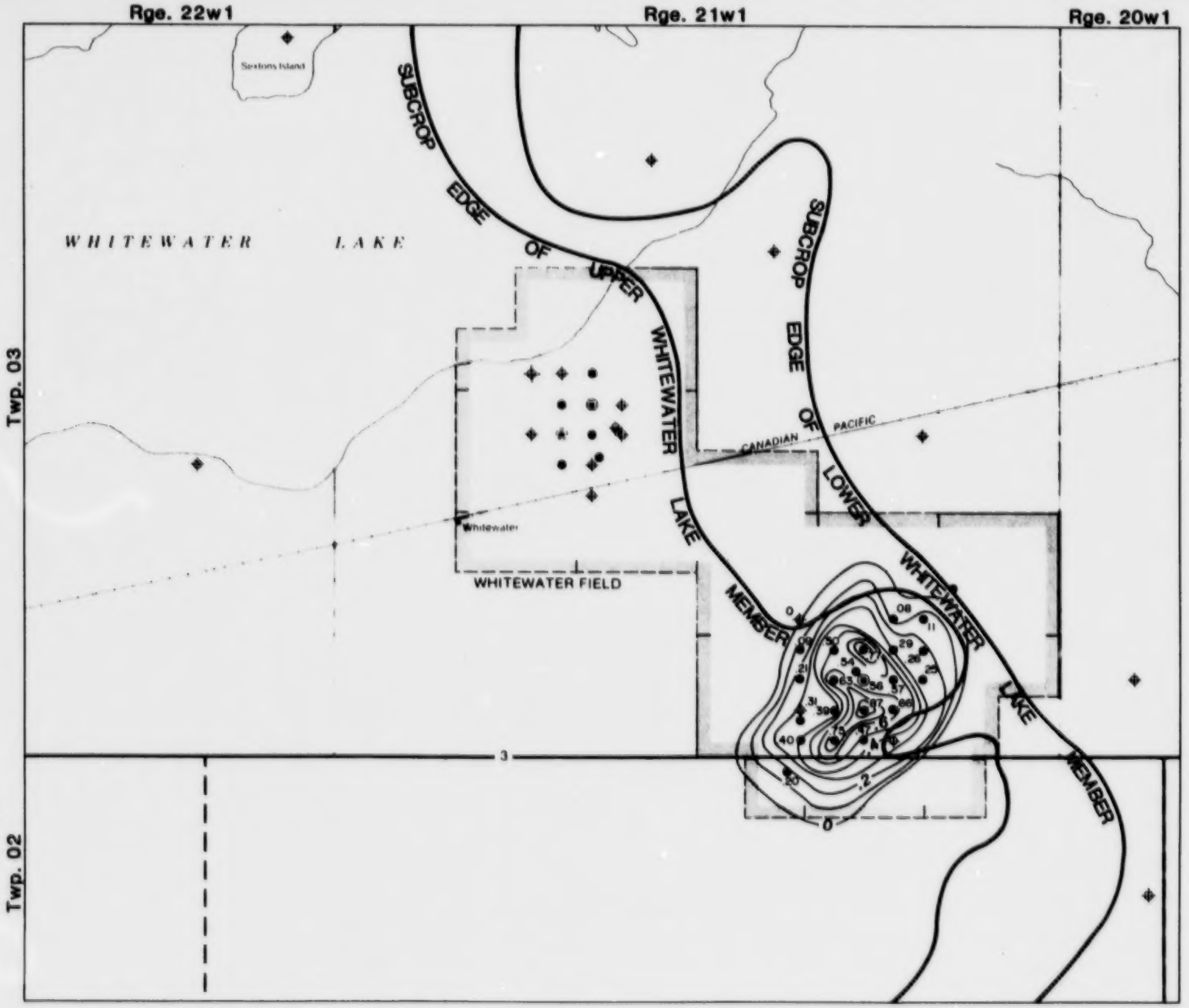

Figure 23: Oil-in-Place per Unit Area Map for Upper and Lower Whitewater Lake Members (contour inteval: 0.1 m^3/m^3)

f) Reservoir Properties

Table 5 lists reservoir properties for the WL B Pool The shrinkage factor (1/Boi) was obtained from an AGAT-Roxy Petroleum Ltd. Reservoir Fluid study for Roxy-Andex et al Whitewater 10-2-3-21 WPM (1983).

The oil recovery factor of 9% in Table 5 was obtained in the following manner. Because the WL B Pool is currently being developed and expanded, the Pool's oil production rate is erratic and an annual WL B Pool production decline rate cannot be calculated. Better oil decline rates can be obtained from individual wells in the Pool. Table 6 lists each producing well in the WL B Pool, with its corresponding period of decline and calculated annual production decline. Production decline rates could not be calculated for several wells because of erratic production and/or lack of sufficient production life. A few wells exhibit very high production decline. These wells appear to be located away from the centre of the WL B Pool and probably reflect production from the edge of the Pool. The average annual production decline in the central portion of the Pool is 13%. In Table 6, locations flagged with an asterisk were used to calculate the 13% annual production decline. Figure 24 shows a typical WL B Pool oil production decline curve for a well in the centre of the Pool (10-2-3-21 WPM). Production from all of the WL B Pool wells was summed up to obtain a group production history plot for the Pool. The 13% annual production decline was applied to this WL B Pool production history plot. Assuming that the lower economic limit for oil production is 0.5 m^3/per day per well, the ultimate recoverable reserves for the WL B Pool are calculated to be 170 704 m^3 oil or 9% of the original oil-in-place (1 906 661 m^3 oil).

Table 7 lists reservoir properties for the Whitewater Lodgepole Virden A Pool. The WL B Pool recovery factor of 9% is assumed to apply to the Virden A Pool.

TABLE 5: Whitewater Lodgepole WL B Pool Reservoir Properties

I. General Information:

1. Year of discovery		1982
2. Number of Wells:	a) Capable of Oil Production	20
	b) Produced during 1985	15
	c) Service	1
	d) Active during 1985	16
	e) Previous Producers	1
3. Spacing		16 ha
4. Average Depth of Producing Zone		804 m KB
5. Crude Oil Quality:	a) Density	861 kg/m^3
	b) Sulphur Content	9.8 g/kg
6. Permeability (cut off 1.0 md)		25 md
7. Initial Pressure (at datum -259 m,ss)		Not Available
Current Pressure (at datum -259 m,ss)		Not Available
9. Recovery Mechanism:		Water Drive

II. Reserves Information:

1. Production Area (A)	718 ha
2. Net Pay (h) (cutoffs: ϕ = 7.5%, k = 1.0 md)	3.5 m
3. Porosity (ϕ)	14 %
4. Connate Water Saturation (Sw)	43 %
5. Shrinkage Factor (1/Boi)*	0.94
6. Original Oil-in-Place	1 906 661 m^3
7. Recovery Factor	9 %
8. Ultimate Recoverable Reserves	170 704 m^3
9. Cumulative Production (to Dec. 31, 1985)	33 136 m^3
10. Remaining Recoverable Reserves (Dec. 31, 1985)	137 568 m^3

* obtained from zero flash test on surface oil sample from the well Roxy-Andex et al Whitewater 10-2-3-21 WPM (producing from Upper and Lower Whitewater Lake Members)

TABLE 6: Whitewater Lodgepole WL B Pool Production Declines

Location	Decline Period	Annual Production Decline(%)
16-33-02-21	insufficient production	
*03-02-03-21	March 1984 - July 1986	21
04-02-03-21	insufficient production	
*05-02-03-21	June 1984 - July 1986	17
*06-02-03-21	June 1984 - July 1986	7
07-02-03-21	March 1985 - May 1986	79
09-02-03-21	erratic production decline	
*10-02-03-21	July 1984 - Juy 1986	16
11-02-03-21	erratic production decline	
A11-02-03-21	insufficient production	
12-02-03-21	March 1984 - July 1986	47
13-02-03-21	November 1984 - July 1986	24
*14-02-03-21	April 1984 - July 1986	14
*15-02-03-21	August 1983 - July 1986	10
*16-02-03-21	May 1982 - July 1986	6
01-03-03-21	insufficient production	
08-03-03-21	Dry and Abandoned	
8A-03-03-21	insufficient production	
09-03-03-21	March 1985 - July 1986	46
16-03-03-21	insufficient production	
01-11-03-21	erratic production decline	
*02-11-03-21	May 1983 - July 1986	16

* production declines used to calculate an average annual production decline of 13% for the WL B Pool

TABLE 7: Whitewater Lodgepole Virden A Pool Reservoir Properties

I. General Information:

		1985
1. Year of discovery		
2. Number of Wells:	a) Capable of Oil Production	1
	b) Produced during 1985	1
	c) Service	0
	d) Active during 1985	1
	e) Previous Producers	0
3. Spacing		16 ha
4. Average Depth of Producing Zone		790 m KB
5. Crude Oil Quality: a) Density		864 kg/m^3
b) Sulphur Content		9.3 g/kg
6. Permeability (cut off 1.0 md)		15 md
7. Initial Pressure (at datum -270 m,ss)		7 400 kPa
Current Pressure (at datum -270 m,ss)		Not Available
9. Recovery Mechanism:		Not Available

II. Reserves Information:

1. Production Area (A)	16 ha
2. Net Pay (h) (cutoffs: ø = 7.5%, k = 1.0 md)	2.0 m
3. Porosity (Ø)	13 %
4. Connate Water Saturation (Sw)	42 %
5. Shrinkage Factor (1/Boi)*	0.89
6. Original Oil-in-Place	21 474 m^3
7. Recovery Factor**	9 %
8. Ultimate Recoverable Reserves	1 933 m^3
9. Cumulative Production (to Dec. 31, 1985)	368 m^3
10. Remaining Recoverable Reserves (Dec. 31, 1985)	1 565 m^3

* obtained from flash test on DST sample from the well Roxy-Andex Whitewater 5-12-3-21 WPM (Upper Virden Member)

** recovery factory for Virden A Pool assumed to be indentical to recovery factor for Lodgeople WL B Pool

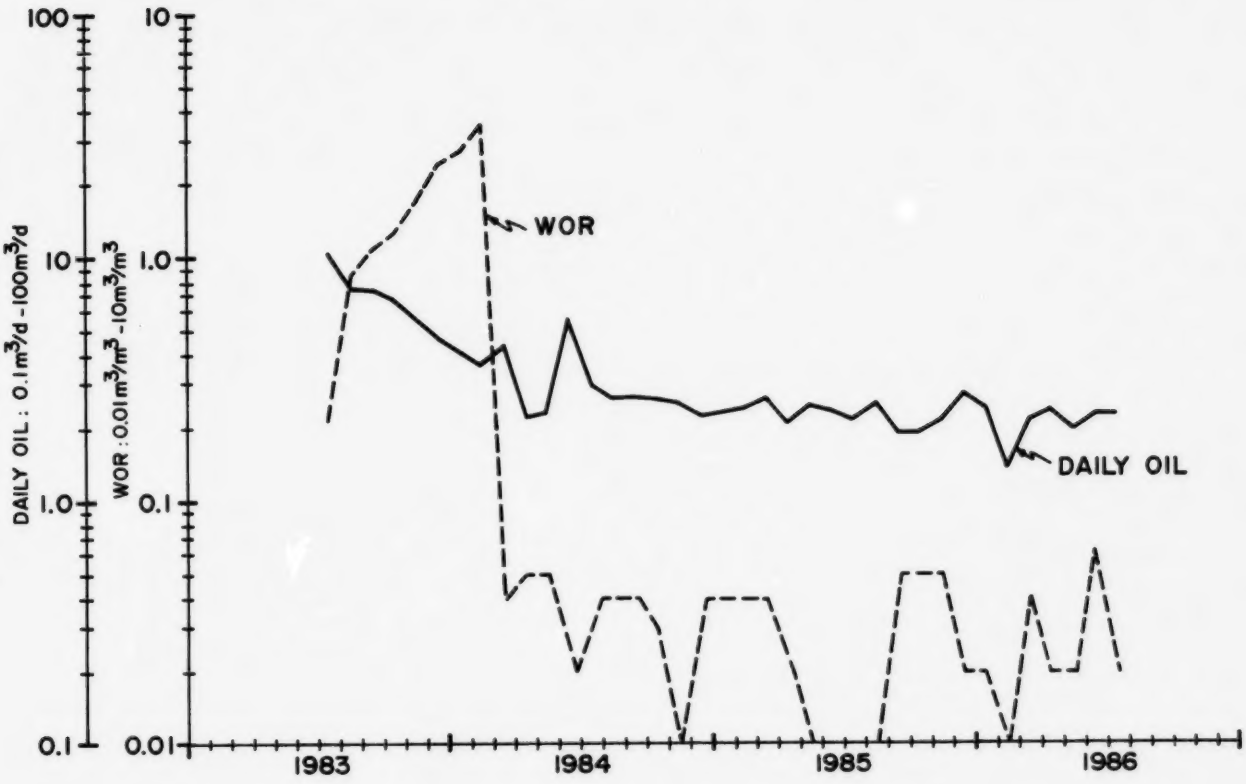

Figure 24: Oil Production Decline Curve for Roxy-Andex et al Whitewater 10-2-3-21 WPM

g) Oil Production/Oil-In-Place Match

Oil-in-place per unit area values were calculated over the perforated intervals for all producers in the WL B Pool. Table 8 lists all of the WL B Pool producers along with their corresponding perforated thicknesses, average daily oil production and oil-in-place per unit area values.

Figure 25 is an oil production versus oil-in-place per unit area plot. Data for the plot was obtained from Table 8. The plot shows that, with the exception of three wells, there is a remarkably good correlation between these two variables (correlation coefficient = 0.86 for 12 of the 15 points). Wells 9-3-3-21 WPM and 12-2-3-21 WPM produce at much higher

rates than expected. These two wells show annual oil production decline rates of 46% and 47% respectively (see Table 6). These very high decline rates indicate that 9-3-3-21 WPM and 12-2-3-21 WPM will produce at much lower rates in the near future. The well 11-2-3-21 WPM produces much less than expected, based on the correlation obtained. No reason for this exception can be given at this time.

The plot on Figure 25 can be used to predict average oil production, based on log responses in the WL B Pool. It also serves as a check on the oil-in-place per unit area calculations for the Pool.

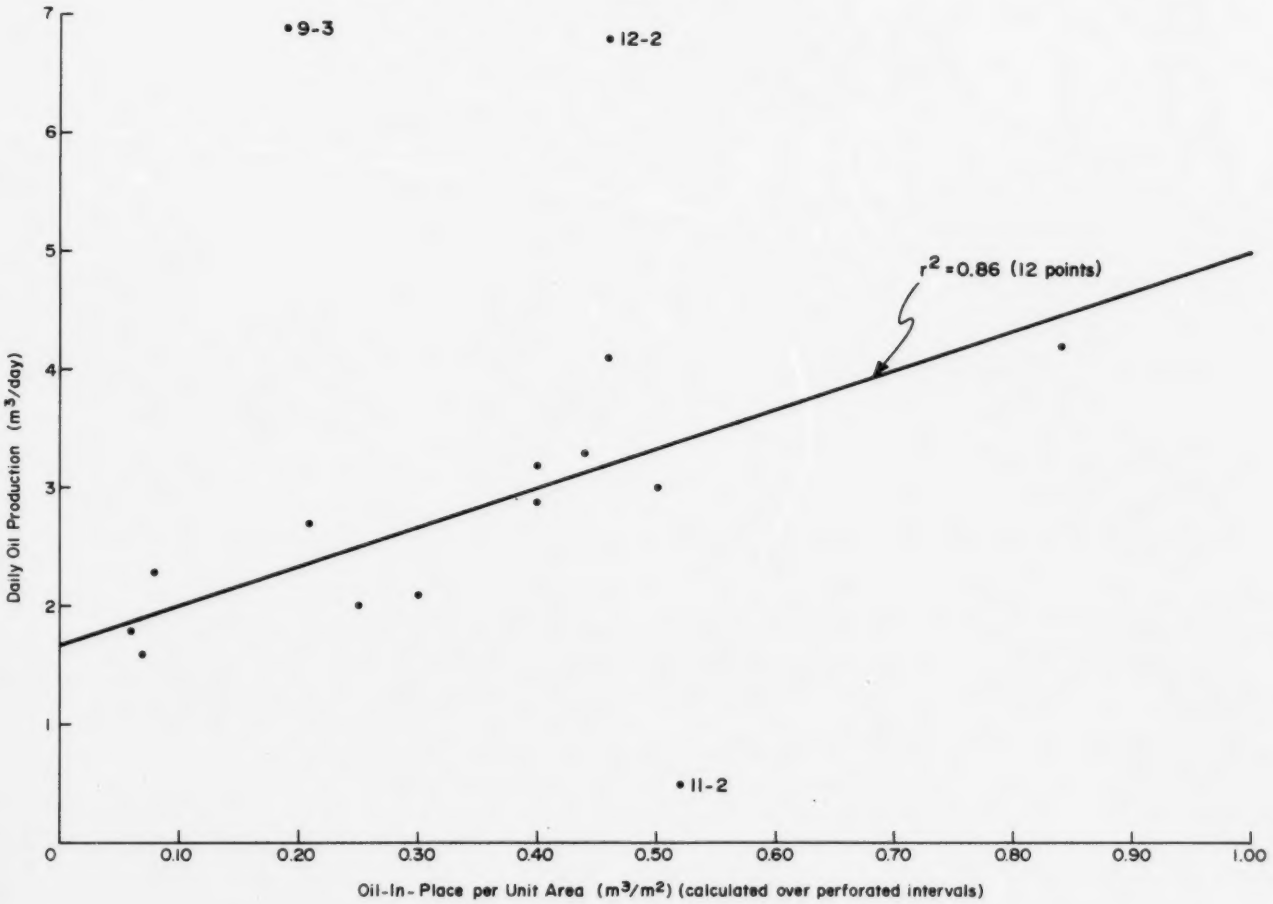

Figure 25: Oil Production Versus Oil-in-Place per Unit Area Plot (Whitewater Lodgepole WL B Pool)

TABLE 8: Oil-in-place Per Unit Area Over Perforated Intervals (WL B Pool)

Location	Metres Perforated Upper Whitewater (m)	Lower Whitewater (m)	Upper Virden (m)	$\phi h(1-Sw)$ (m^3/m^2)	Average Oil Production* (m^3/day)
16-33-02-21	4.0	0	0	0.24	-
03-02-03-21	6.5	0	0	0.44	3.3
04-02-03-21	4.5	0	0	0.40	-
05-02-03-21	7.0	0	0	0.30	2.1
06-02-03-21	7.0	2.0	0	0.84	4.2
07-02-03-21	6.0	0	0	0.40	2.9
09-02-03-21	0	2.0	1.5	0.25	2.0
10-02-03-21	8.0	3.0	0	0.40	3.2
11-02-03-21	4.5	0	0	0.51	0.5
A11-02-03-21	3.6	3.8	0	0.44	-
12-02-03-21	7.5	0	0	0.46	6.8
13-02-03-21	4.2	2.0	0	0.46	4.1
14-02-03-21	5.0	1.0	0	0.50	3.0
15-02-03-21	6.5	2.8	0	0.27	2.1
16-02-03-21	1.3	7.3	0	0.08	2.3
01-03-03-21	7.0	0	0	0.36	-
08-03-03-21	Not Perforated				
8A-03-03-21	Omitted/sonic log inaccuracy problem				
09-03-03-21	5.5	0	0	0.19	6.9
16-03-03-21	3.5	0	0	0.07	-
01-11-03-21	6.0	3.5	0	0.07	1.6
02-11-03-21	4.5	2.0	0	0.06	1.8

* wells which produce for less than 12 months are excluded.

CONCLUSION

Mississippian strata within the Whitewater Field study area represent part of a complex transgressive-regressive cycle of deposition that occurred during early Mississippian (Lodgepole) time.

Production in the Field is obtained from the Upper and Lower Whitewater Lake Members and, to a much lesser extent, the Upper Virden Member. Lithologically, these members consist of a cyclic repetition of porous oolitic packstone/grainstones.

The Whitewater Field appears to be primarily stratigraphically controlled. Truncation of the porous reservoir beds at the Mississippian erosion surface has resulted in the formation of a regional stratigraphic trap setting.

Local accumulation occurs mainly within "paleotopographic highs" and is modified by porosity/permeability variations related to alteration at the Mississippian unconformity surface.

Future Potential

Based on geologic and engineering data, it appears that there are some future development possibilities within existing Pools of the Whitewater Field. Future Upper Whitewater Lake Member development locations proposed within the WL B Pool, include, (in decreasing order of hydrocarbon potential): 13-34-2-21 WPM, 12-34-2-21 WPM, 14-34-2-21 WPM, 2-3-3-21 WPM and 3-11-3-21 WPM. The location 8-2-3-21 WPM shows some Lower Whitewater Lake Member potential.

It is likely that other, as yet undiscovered "paleotopographic highs" exist within the regional stratigraphic trap setting along the erosion edges of the Whitewater Lake and Virden Members subcrop belts. Future exploration should be directed to the discovery of these erosional "highs" within the subcrop belts of these Members.

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APPENDIX

Selected Core Descriptions

Roxy Andex Whitewater
3-2-3-21 WPM

Upper Whitewater Lake Member

807.0 - 807.8 m	Dolomite: light brown to pink, dense, bioclastic, anhydrite banding in first 0.4 m.
807.8 - 808.0 m	Dolomite: light brown, bioclastic, fair intergranular porosity, oil stained.
808.0 - 813.5 m	Packstone: light brown to buff, bioclastic (crinoid, brachiopod fragments), oolitic in part (calcite cement), good intergranular and pinpoint porosity, oil stained, tight near base.
813.5 - 813.7 m	Shale: rusty red, calcareous, fissile, fossiliferous.
813.7 - 815.5 m	Wackestone/Packstone: brown, bioclastic (coral, brachiopod fragments), calcite cement stylolitic, fair to good intergranular porosity, patchy oil staining.

Lower Whitewater Lake Member

815.5 - 820.0 m	Wackestone/Mudstone: red, calcareous, bioclastic (crinoid and brachiopod fragments) oolitic to pelloidal, calcite cement, good moldic porosity, local patchy oil staining; interbedded with shale.
820.0 - 820.2 m	Shale: light green, calcareous, fissile, fossiliferous (brachiopod fragments), minor pyrite.

820.2 - 822.0 m	Wackestone/Packstone: brown, oolitic, calcite cement, fossiliferous (minor), good moldic and intergranular porosity, banded oil staining.
822.0 - 823.5 m	Oolitic Packstone/Grainstone: brown, brachiopod fragments, good moldic and inter-oolitic porosity.
823.5 - 825.0 m	Mudstone/Wackestone: light green, brachiopod and coral fragments, white chert nodules (<0.5 cm), fair to poor intergranular porosity, oil stained.

Roxy-Andex Whitewater

5-2-3-21 WPM

Upper Whitewater Lake Member

807.0 - 807.7 m — Wackestone/Packstone: brown, coral and brachiopod fragments, calcite cement, fair to good intergranular porosity, patchy oil staining.

807.7 - 809.5 m — Wackestone/Packstone: buff to pink, dolomitic, brachiopod and coral fragments, fair to good intergranular and pinpoint porosity, patchy oil staining; grades into mudstone near base, light green and maroon mottled, vertical fracturing, anhydrite bands and blebs increasing near base.

809.5 - 810.5 m — Bioclastic Wackestone/Packstone: brown to buff, crinoid, brachiopod and coral fragments, calcite cement, some anhydrite infilling, fair intergranular and pinpoint porosity, no oil staining.

Lower Whitewater Lake Member

810.5 - 811.3 m — Interbedded Shale/Mudstone/Wackestone: light grey, pink and maroon mottled, anhydrite infilling, brachiopod and shell fragments, some moldic porosity, no oil shows.

811.3 - 812.25 m — Wackestone: pink, coral and brachiopod fragments, calcite cement, vertical fracturing (infilled), good intergranular porosity, banded oil staining.

812.25 - 816.2 m — Interbedded Shale/Mudstone and Wackestone/Packstone: Shale/Mudstone: red and maroon mottled, calcareous, fissile, bioturbated. Wackestone/Packstone: pink, coral and brachiopod fragments, calcite cement, stylolitic, fair to good porosity, patchy oil staining.

816.2 - 816.9 m — Packstone: green to buff, calcite cement, good moldic and intergranular porosity, some banded oil staining.

816.9 - 817.65 m — Shale: crinoid and brachiopod fragments, calcareous, fissile.

817.65 - 820.25 m — Oolitic Packstone/Grainstone: buff, brachiopod fragments, calcite cement, stylolitic, good intergranular porosity, banded and patchy oil staining.

820.25 - 823.5 m — Interbedded Mudstone and Packstone/Grainstone: Mudstone: brachiopod, coral and shell fragments, calcareous. Packstone/Grainstone: buff to light green, brachiopod, coral and shell fragments, calcite cement, anhydrite infilling, fair to good intergranular porosity, oil stained.

Upper Virden Member

823.5 - 825.0 m — Packstone/Grainstone: chalk clasts (3 - 5 cm), calcite cement, patchy oil staining, grades into mudstone near base.

Roxy-Andex Whitewater
6-2-3-21 WPM

Upper Whitewater Member

803.0 - 804.5 m — Anhydrite: grey to blue-grey, dense; interbedded with Dolomite: brachiopod fragments, some oil-staining, vertical fracturing (infilled), chert nodules (0.5 - 1 mm); interbedded with shale; slightly fissile.

804.5 - 811.5 m — Wackestone/Packstone: buff, shell and coral fragments, calcite cement, fair to good intergranular and moldic porosity, oil-stained in part; tight silicified streak (805.93 - 806.70 m), buff to light grey, bedded and in nodules (3 - 5 cm).

Lower Whitewater Lake Member

811.5 - 815.55 m — Interbedded Wackestone/Packstone and Bioclastic Shale/Mudstone:
Wackestone/Packstone: buff, coral and brachiopod fragments, calcite cemented, fair to good intergranular and moldic porosity, banded oil staining.
Bioclastic Shale/Mudstone: maroon and red, mottled, coral and brachiopod fragments, calcareous, some iron staining.

815.55 - 818.95 m — Shale: red and maroon, mottled, calcareous, bioclastic interbedded with oolitic packstone/grainstone: maroon, brachiopod, coral and crinoid fragments, poor vuggy to moldic porosity, no oil staining.

818.95 - 821.0 m — Oolitic Grainstone: buff, coral and shell fragments, stylolitic, good intergranular porosity, some vuggy and moldic porosity, oil-stained throughout; interbedded with mudstone/wackestone, green, coral and crinoid fragments, calcareous.

Cdn Roxy-Andex et al Whitewater
10-2-3-21 WPM

Upper Whitewater Lake Member

800.5 - 806.45 m — Oolitic Wackestone/Packstone: buff, coral, brachiopod and crinoid fragments, calcite cement, some anhydrite infilling, good intergranular and moldic porosity with some vuggy porosity, no oil show; interbedded with wackestone, red and maroon, mottled, crinoid and brachiopod fragments, some nodules of anhydrite (1.5 - 2 cm), fair intergranular and moldic porosity, oil stained.

Lower Whitewater Lake Member

806.45 - 807.4 m — Mudstone/Shale: red (iron stained) and maroon, mottled, bioclastic, calcareous, fissile; some interbedding of wackestone.

807.4 - 808.6 m — Wackestone/Packstone: buff to brown, crinoid, brachiopod and coral fragments, calcite cement, iron stained, fair intergranular porosity, oil stained.

808.6 - 812.2 m — Mudstone/Shale: red (iron stained) to maroon, fissile, brachiopod and shell fragments, calcareous.

812.2 - 814.45 m — Oolitic Grainstone: buff, crinoid fragments, vertical fracturing, stylolitic, fair to good intergranular porosity, oil stained.

814.45 - 816.0 m — Mudstone/Wackestone: light grey, crinoid and shell fragments, tight, calcareous, chert nodules clasts (<0.5 cm), minor horizontal and vertical pyrite-filled fractures.

816.0 - 818.5 m — Oolitic Packstone/Grainstone: buff to brown, shell fragments, fair to good intergranular porosity, oil-stained; interbedded with mudstone/wackestone, light green, calcareous, bioclastic.

Cdn. Roxy-Andex Whitewater
14-2-3-21 WPM

Upper Whitewater Lake Member

787.5 - 789.0 m	Anhydrite: grey to blue, dolomitic, local poor pinpoint porosity, patchy oil staining.
789.0 - 789.85 m	Wackestone: buff to brown, brachiopod and shell fragments, local siliceous bands, nodules of blue-grey anhydrite, poor to fair pinpoint porosity, patchy oil stain.
789.85 - 790.85 m	Wackestone: pink to brown, dolomitic, local siliceous bands (as above), nodules of blue-grey anhydrite, poor to fair pinpoint porosity.
790.85 - 793.9 m	Packstone: buff to brown, crinoid, brachiopod and coral fragments, calcite cement, some anhydrite infilling, good intergranular and moldic porosity, banded oil staining.
793.9 - 795.45 m	Packstone: pink to buff, brachiopod and coral fragments, calcite cement, hematite staining, fair to good intergranular and moldic porosity, oil stained.

Lower Whitewater Lake Member

795.45 - 795.8 m	Mudstone/Shale: red, hematite staining, calcareous.
795.8 - 796.5 m	Packstone: buff; as above.
796.5 - 797.55 m	Mudstone: pink and purple, mottled, coral and brachiopod fragments, hematite staining.

797.55 - 798.0 m	Wackestone/Packstone: coral and brachiopod fragments, calcite cement, fair to good intergranular porosity, good moldic and vuggy porosity, oil stained in places.
798.0 - 798.85 m	Mudstone/Shale: red, brachiopod fragments, calcareous, hematite staining, fissile.
798.85 - 799.25 m	Wackestone/Packstone: pink to buff, fair vuggy porosity, some patchy oil staining.
799.25 - 799.5 m	Mudstone/Shale: red, as above.
799.5 - 800.0 m	Packstone: buff to brown, crinoid and shell fragments, calcite cement, fragmental, stylolitic, fair to good moldic and vuggy porosity, oil-stained.
800.0 - 802.4 m	Mudstone/Shale: red and purple, mottled, brachiopod fragments, calcareous, hematite stained.
802.4 - 803.0 m	Wackestone/Packstone: pink to buff, brachiopod fragments, calcite cement, fair intergranular porosity.
803.0 - 803.85 m	Mudstone/Shale: red and purple, mottled, as above.
803.85 - 805.5 m	Oolitic Packstone: crinoid fragments?, stylolitic, fair intergranular and fair to good vuggy porosity, oil stained.

Chevron Whitewater

10-17-3-21 WPM

Lower Amaranth (Red Beds)

2498' - 2521' (761.39 - 768.4 m)	Siltstone: brick red, white to grey anhydrite clasts (3 - 5 cm), argillaceous.

Upper Whitewater Lake Member

2521' - 2521.7' (768.4 - 768.61 m)	Anhydrite: pink
2521.7' - 2529.5' (768.61 - 770.99 m)	Dolomite: dense, horizontal fractures infilled with blue anhydrite, bioclastic, some oil staining, blue anhydrite band (2524.5' - 2525').
2529.5' - 2535' (770.99 - 772.67 m)	Dolomite: pink, dense, horizontal fractures.
2535' - 2544.3' (772.67 - 775.5 m)	Wackestone: grey to pink, dolomitic, bioclastic, trace white chert clasts (< 0.5 cm), grey to green shale partings (1 - 2") at 2542 and 2544', vertical and horizontal fractures, more calcareous near base, fair intergranular and pinpoint porosity, some oil staining.

Lower Whitewater Lake Member

2544.3' - 2548' (775.5 - 776.63 m)	Wackestone grading to Packestone: grey to pink, maroon shale bands, bioclastic, stylolitic, fair intergranular and vuggy porosity, no oil show.

Chevron Whitewater

16-17-3-21 WPM

Lower Amaranth (Red Beds)

2491' - 2492' (759.26 - 759.56 m)	Siltstone: Brick red, white to grey anhydrite clasts (3 - 5 cm), argillaceous.

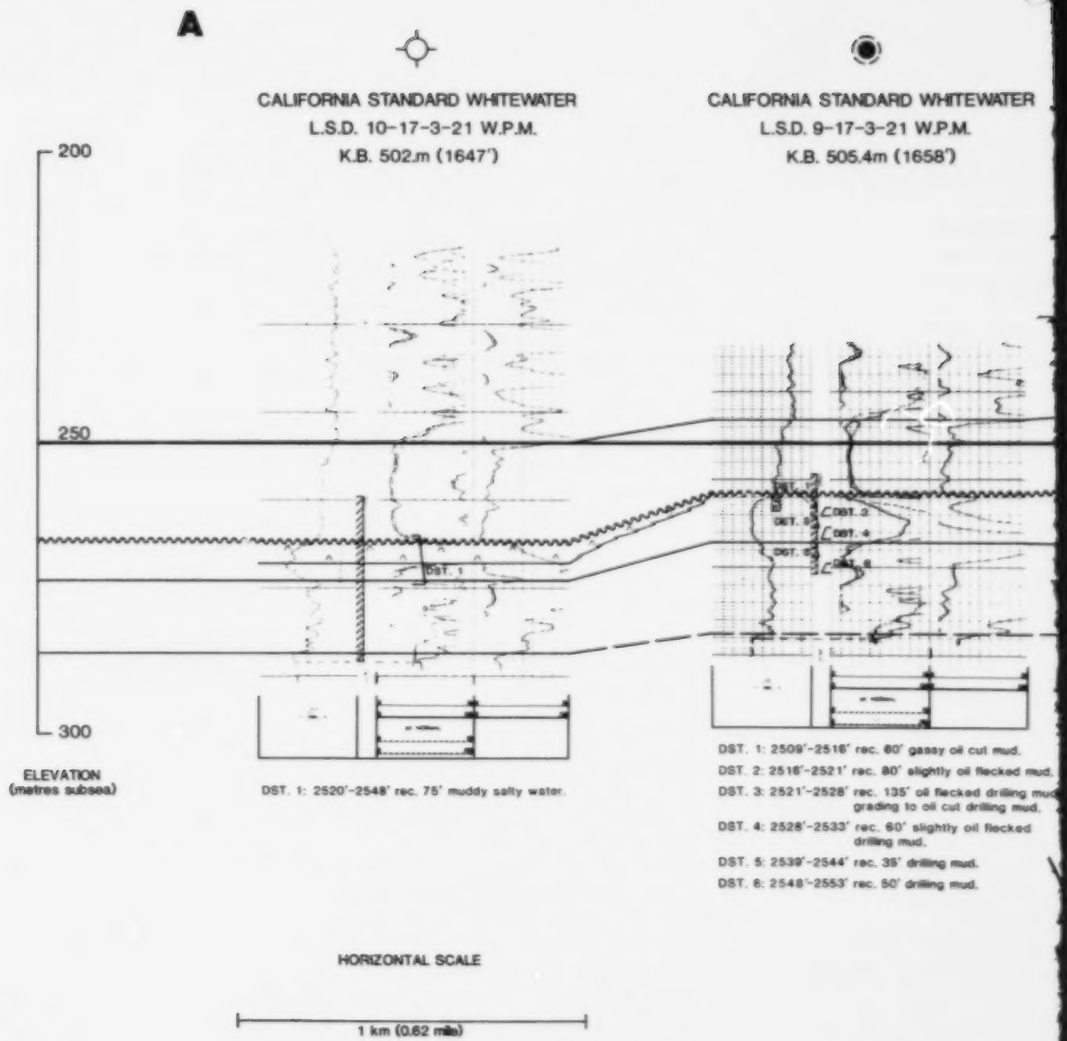
Upper Whitewater Lake Member

2492' - 2501' (759.56 - 762.30 m)	Dolomite: grey, dense brecciated near top, white to purple anhydrite in nodules, bands and fracture-filling; few interbeds of oolitic packestone/grainstone white, fossiliferous.
2501' - 2502' (762.30 -762.61 m)	Oolitic Wackestone/Packestone: pink to brown bioclastic.
2502' - 2511' (762.61 - 765.35 m)	Oolitic Packstone/Grainstone: brown, bioclastic, anhydrite infill in places, good interparticle and pinpoint porosity, oil stain throughout.
2511'- 2516.7' (765.35 - 767.09 m)	Wackestone/Packstone: brown, slightly dolomitic, some anhydrite infilling, bioclastic, fair to good pinpoint and intergranular porosity, oil stain.
2516.7' - 2521' (767.09 - 768.4 m)	Core missing
2521' - 2524' (768.4 - 769.32 m)	Wackestone: brown, fair to good pinpoint and intergranular porosity, oil stain.
2524' - 2524.5' (769.32 - 769.47 m)	Chert: grey to brown, dense

2524.5' - 2533.5' (769.47 -772.21 m)	Wackestone/Packstone: brown, bioclastic, fair intergranular and pinpoint porosity, oil stained; interbedded with dolomitic limestone, buff, dense, no oil show.
2533.5' - 2534.5' (772.21 -772.52 m)	Packstone/Grainstone: pink to brown, bioclastic, anhydritic, some oil staining.
2534.5' - 2541.5' (772.52 - 774.65 m)	Wackestone/Packstone: light grey, anhydrite infilling, white chert nodules (<0.5 cm), blebs of anhydrite (3 - 5 cm), bioclastic near base, fair to good pinpoint and intergranular porosity, oil-stained where porosity preserved.

Lower Whitewater

2541.5' - 2542' (774.65 -774.8 m)	Wackestone/Mudstone: dolomitic, argillaceous, bioclastic, white nodules (<0.5 cm), anhydrite infilling.


A
CALIFORNIA STANDARD WHITEWATER
L.S.D. 10-17-3-21 W.P.M.
K.B. 502.m (1647')
CALIFORNIA STANDARD WHITEWATER
L.S.D. 9-17-3-21 W.P.M.
K.B. 505.4m (1658')
200
250
300
ELEVATION
(metres subsea)
DST. 1
DST. 2
DST. 3
DST. 4
DST. 5
DST. 6
DST. 1: 2520'-2548' rec. 75' muddy salty water.
DST. 1: 2509'-2516' rec. 60' gassy oil cut mud.
DST. 2: 2516'-2521' rec. 80' slightly oil flecked mud.
DST. 3: 2521'-2528' rec. 135' oil flecked drilling mud grading to oil cut drilling mud.
DST. 4: 2528'-2533' rec. 60' slightly oil flecked drilling mud.
DST. 5: 2539'-2544' rec. 35' drilling mud.
DST. 6: 2548'-2553' rec. 50' drilling mud.
HORIZONTAL SCALE
1 km (0.62 mile)

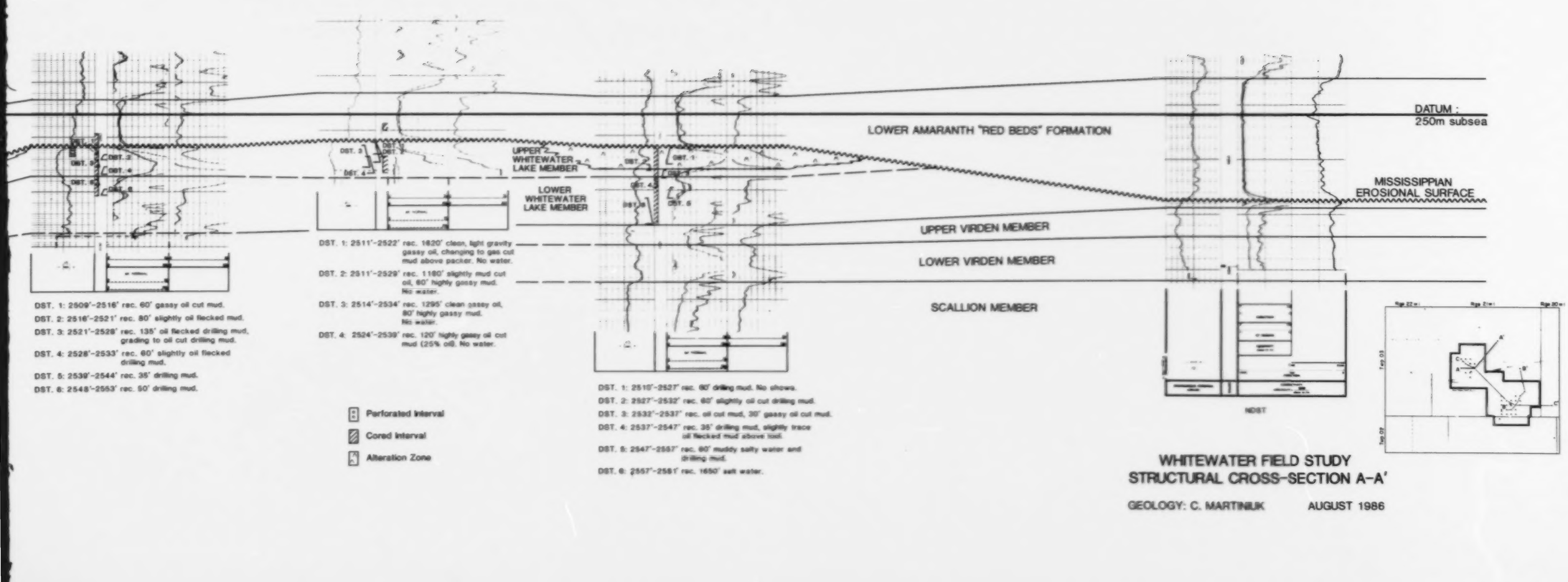
A'

CALIFORNIA STANDARD WHITEWATER
L.S.D. 9-17-3-21 W.P.M.
K.B. 505.4m (1658')

CALIFORNIA STANDARD WHITEWATER
L.S.D. 12-16-3-21 W.P.M.
K.B. 507.2m (1664')

CALIFORNIA STANDARD WHITEWATER
L.S.D. 11-16-3-21 W.P.M.
K.B. 506.3m (1661')

SDC ARGOLA N. WHITEWATER PROV.
L.S.D. 2-27-3- 21 W.P.M.
K.B. 499.6m (1639')



DST. 1: 2509'-2516' rec. 60' gassy oil cut mud.
DST. 2: 2516'-2521' rec. 80' slightly oil flecked mud.
DST. 3: 2521'-2528' rec. 135' oil flecked drilling mud, grading to oil cut drilling mud.
DST. 4: 2528'-2533' rec. 60' slightly oil flecked drilling mud.
DST. 5: 2539'-2544' rec. 35' drilling mud.
DST. 6: 2548'-2553' rec. 50' drilling mud.

DST. 1: 2511'-2522' rec. 1620' clean, light gravity gassy oil, changing to gas cut mud above packer. No water.
DST. 2: 2511'-2529' rec. 1180' slightly mud cut oil, 60' highly gassy mud. No water.
DST. 3: 2514'-2534' rec. 1295' clean gassy oil, 80' highly gassy mud. No water.
DST. 4: 2524'-2539' rec. 120' highly gassy oil cut mud (25% oil). No water.

DST. 1: 2510'-2527' rec. 60' drilling mud. No shows.
DST. 2: 2527'-2532' rec. 60' slightly oil cut drilling mud.
DST. 3: 2532'-2537' rec. oil cut mud, 30' gassy oil cut mud.
DST. 4: 2537'-2547' rec. 35' drilling mud, slightly trace oil flecked mud above tool.
DST. 5: 2547'-2557' rec. 60' muddy salty water and drilling mud.
DST. 6: 2557'-2581' rec. 1650' salt water.

Perforated Interval
Cored Interval
Alteration Zone

WHITEWATER FIELD STUDY
STRUCTURAL CROSS-SECTION A-A'

GEOLOGY: C. MARTINIUK AUGUST 1986

B

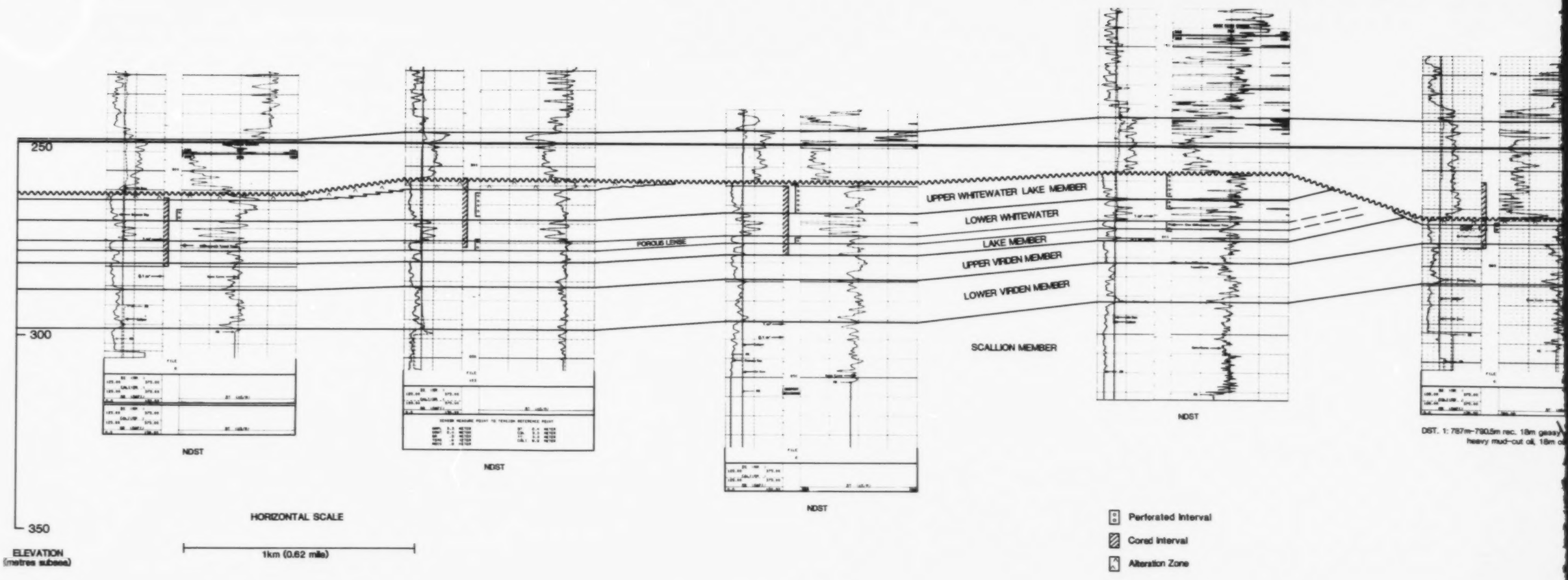
ROXY-ANDEX WHITEWATER
L.S.D. 5-2-3-21 W.P.M.
K.B. 543.08m

ROXY-ANDEX WHITEWATER
L.S.D. 6-2-3-21 W.P.M.
K.B. 545.1m

ROXY-ANDEX et al WHITEWATER
L.S.D. 10-2-3-21 W.P.M.
K.B. 540.1m

ROXY-ANDEX et al WHITEWATER
L.S.D. 1-11-3-21 W.P.M.
K.B. 526.4m

ROXY-ANDEX WHITE
L.S.D. 5-12-3-21
K.B. 519.64m



DST. 1: 787m–790.5m rec. 18m geasy
heavy mud-cut oil, 18m c

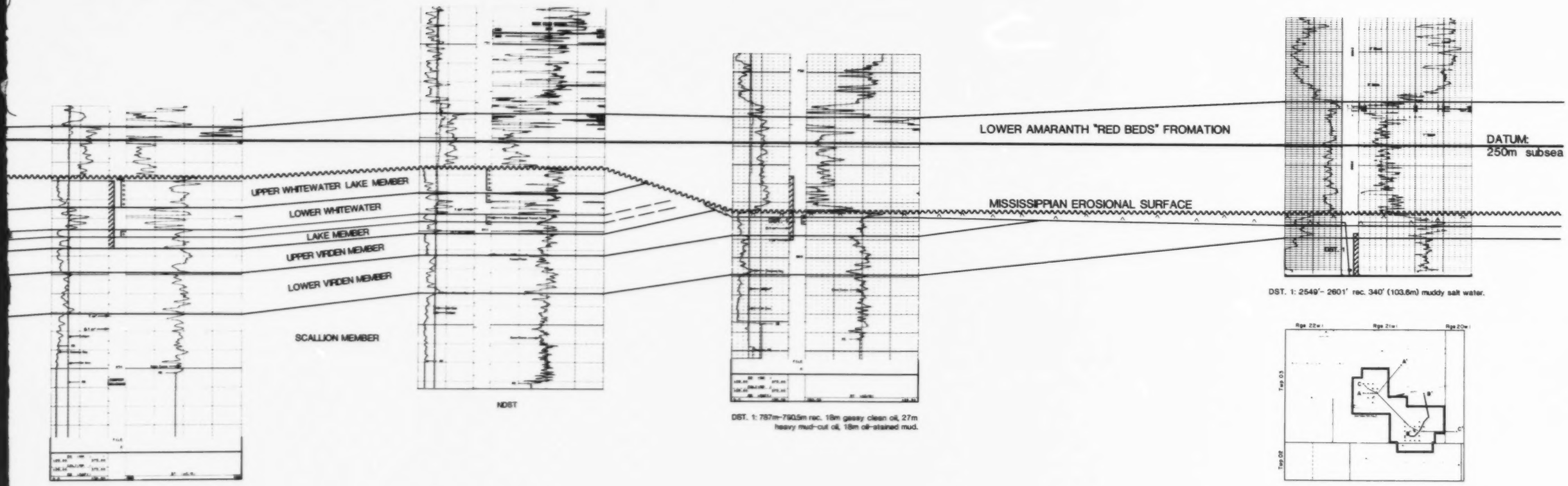
B'

ROXY-ANDEX et al WHITEWATER
L.S.D. 10-2-3-21 W.P.M.
K.B. 540.1m

ROXY-ANDEX et al WHITEWATER
L.S.D. 1-11-3-21 W.P.M.
K.B. 526.4m

ROXY-ANDEX WHITEWATER
L.S.D. 5-12-3-21 W.P.M.
K.B. 519.64m

SAM. GRT. PLNS. E. WHITEWATER PROV.
L.S.D. 9-14-3-21 W.P.M.
K.B. 506.3m (1661')



NDST

NDST

DST. 1: 787m-790.5m rec. 18m gassy clean oil, 27m heavy mud-cut oil, 18m oil-stained mud.

DST. 1: 2549'- 2601' rec. 340' (103.6m) muddy salt water.

Perforated Interval

Cored Interval

Alteration Zone

WHITEWATER FIELD STUDY
STRUCTURAL CROSS-SECTION B-B'

GEOLOGY: C. MARTINIUK AUGUST 1986

c

CALIFORNIA STANDARD WHITEWATER
L.S.D. 2-20-3-21 W.P.M.
K.B. : 499.3m (1638')

CALIFORNIA STANDARD WHITEWATER
L.S.D. 16-17-3-21 W.P.M.
K.B. : 501.4m (1645')

CALIFORNIA STANDARD WHITEWATER
L.S.D. 11-16-3-21 W.P.M.
K.B. : 506.3m (1661')

ROXY-ANDE
L.S.D. 13-2
K.B.

200

250

300

ELEVATION
(metres subsea)

LOWER AMARANTH "RED BEDS" FORMATION

MISSISSIPPIAN EROSIONAL SURFACE

UPPER WHITEWATER LAKE MEMBER

POROUS LENSE

DST. 1: 2511'-2523' rec. 30' oil flecked drilling mud.
DST. 2: 2523'-2548' rec. 1050' brackish

DST. 1: 2494'- 2511' rec. 1410' clean sweet oil.
DST. 2: 2511'-2521' rec. 1145' clean gas cut oil.
DST. 3: 2521'-2531' rec. 30' gas cut mud and 240' oil and gas cut mud.

DST. 1: 2510'-2527' rec. 60' drilling mud. No shows.
DST. 2: 2527'-2532' rec. 60' slightly oil cut drilling mud.
DST. 3: 2532'-2537' rec. 60' oil cut mud, 30' gassy oil cut mud.
DST. 4: 2537'-2547' rec. 35' drilling mud, slightly trace oil flecked mud.
DST. 5: 2547'-2557' rec. 60' muddy salt water and drilling mud.
DST. 6: 2557'-2581' rec. 1650' salt water.

HORIZONTAL SCALE

1 km (0.62 mile)

Perforated Interval
Cored Interval
Alteration Zone

C'

ROXY-ANDEX WHITEWATER
L.S.D. 13-2-3-21 W.P.M.
K.B.: 532.9m

ROXY-ANDEX et al WHITEWATER
L.S.D. 10-2-3-21 W.P.M.
K.B.: 540.1m

SAMEDAN HAMOIL BOISSEVAIN
L.S.D. 10-6-3-20 W.P.M.
K.B.: 504.7m(1774')

DATUM:
250m subsea

AMARANTH "RED BEDS" FORMATION

ISSIPPIAN EROSIONAL SURFACE

POROUS LENSE

UPPER WHITEWATER LAKE MEMBER

LOWER WHITEWATER LAKE MEMBER

UPPER VIRDEN MEMBER

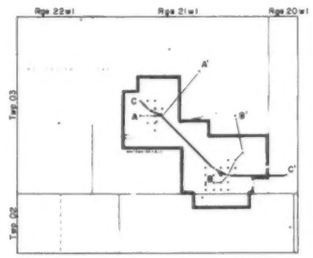
LOWER VIRDEN MEMBER

SCALLION MEMBER

NDST

NDST

NDST



Perforated Interval

Cored Interval

Alteration Zone

WHITEWATER FIELD STUDY
STRUCTURAL CROSS-SECTION C-C'

GEOLOGY: C. MARTINIUK AUGUST 1986

SAPPHIRE WHITEWATER #1
8-14-3-22 W.P.M.
K.B. 1640'

ROXY-ANDEX WHITEWATER
6-2-3-21 W.P.M.
K.B. 545.1m

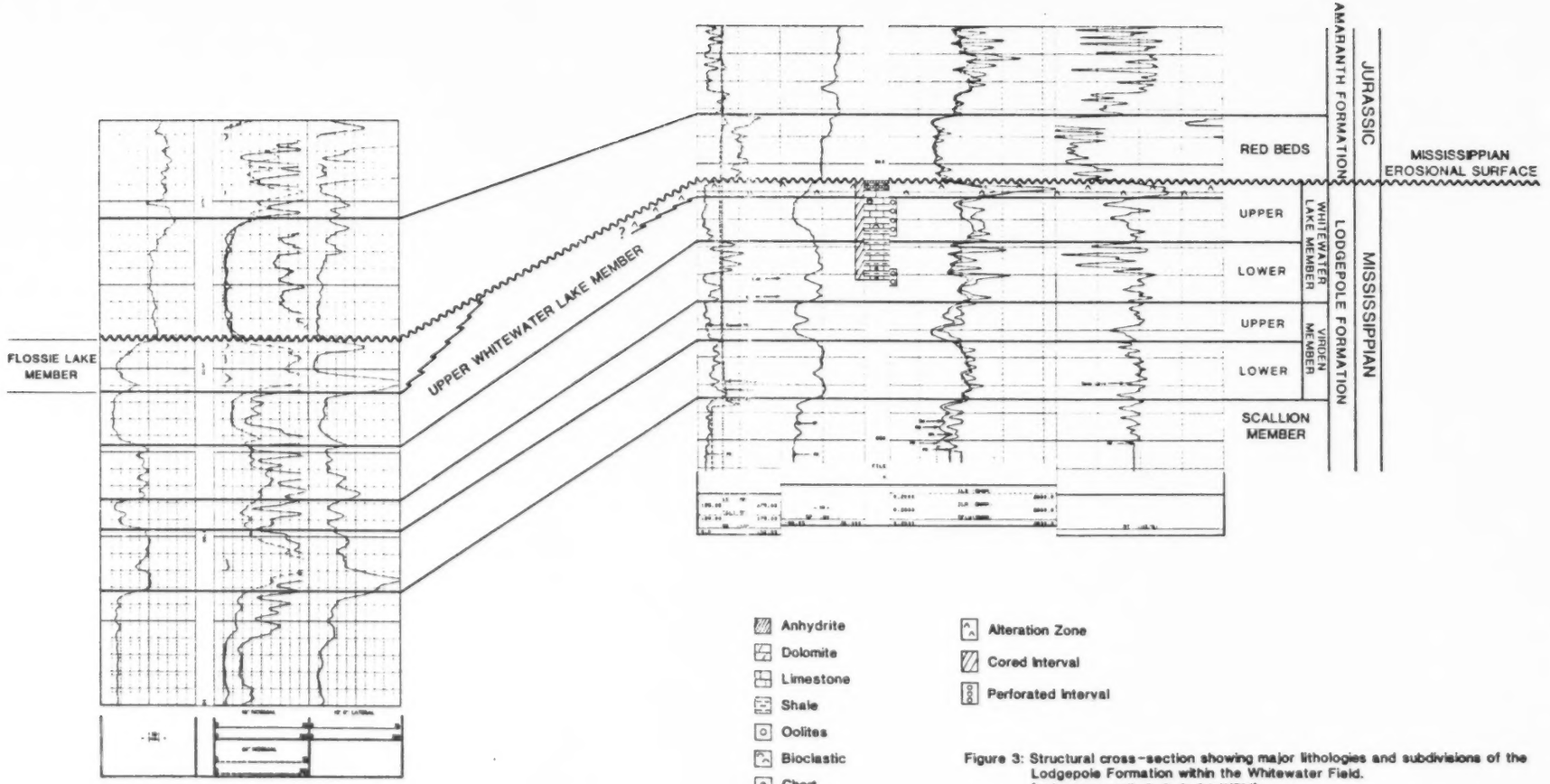


Figure 3: Structural cross-section showing major lithologies and subdivisions of the Lodgepole Formation within the Whitewater Field.
(reference well: 6-2-3-21 WPM)